# R&D in the National system of innovation: A system dynamics model

By

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**SUMMARY**

**R&D IN THE NATIONAL SYSTEM OF INNOVATION:
A SYSTEM DYNAMICS MODEL**

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There exist some concern regarding the sustainability of the production of R&D output and R&D capacity in South Africa. Recent trends indicated evidence of disinvestments and decay of South Africa's R&D capacity.

Questions arise concerning the detrimental effects these trends could have on South Africa's ability to generate R&D output. As problems are addressed insufficiently and the system is allowed to decay, the costs of rebuilding the system might increase even further.

The main research of objective of this thesis is to develop a computer simulation program of R&D performance and the creation of R&D output in the NSI. This model will in turn produce a tool to be used for policy testing, what-if scenario testing or policy optimisation.

The purpose of the model is to simulate R&D output generated in the South African system of innovation and to model and explain the effect the presence/lack of long-term investment in R&D and R&D resources could have on the system's ability to produce R&D output.

In developing this model and by using the corresponding simulation programme, decision-makers in government and industry are provided with a tool to analyse policy alternatives. The model will provide a better understanding of the interrelationships between different elements of the NSI, in particular those interacting as funders and performers of R&D. This model will also aid decision makers in enhancing the efficiency of addressing problem areas within the South African R&D system.

The contribution made by this thesis to the body of knowledge is that the development of a system dynamic model will result in the establishment of a dynamic hypothesis of the development of new knowledge through R&D in an R&D performing sector. The dynamic hypothesis will in turn lead to a method for modelling the effect of R&D investment on the development of an R&D capacity, i.e. the system's ability to absorbed knowledge and produce R&D output. The above is essentially a dynamic description of the process around creating and absorbing knowledge through R&D activities.

Keywords: System Dynamics, R&D, South Africa, National System of Innovation, Research output, absorption of knowledge

**DECLARATION**

I declare that the thesis, which I hereby submit for the degree Philosophiae Doctor (Engineering Management) at the University of Pretoria, is my own work and has not been previously submitted by me for a degree at another University.

_________________________________

Sara S Grobbelaar

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## Glossary

| Term | Explanation |
| --- | --- |
| GDP | Gross Domestic Product |
| R&D | Research and Development |
| NSI | National System of Innovation |
| S&T | Science and Technology |
| HSRC | Human Science Research Council |
| FRD | Foundation for Research and Development |
| OECD | Organisation for Economic Co-operation and Development |
| HES | Higher Education Sector |
| SAPSE | South African Post Secondary Educations |
| FTE | Full Time Equivalent |
| USPTO | United States Patent Office |
| CLD | Casual Loop Diagram |
| ROI | Return on Investment |
| NESTI | National Experts on Science and Technology Indicators |
| TPP | Technological Product and Process |
| GDER | Gross Domestic Expenditure on Research |
| FDI | Foreign Direct Investment |
| BRD | Degree of involvement in R&D in the private business sector |
| EM | Employment in technology-oriented programs |
| EME | Engineers/scientists in R&D programs |
| EDU | Total education expenditures |
| EDUT | Tertiary education expenditures |
| MAS | Masculinity Index |
| IND | Individualism Index |
| PDI | Power Distance Index |
| UAV | Uncertainty Avoidance Index |
| PPP | Purchasing Power Parity |
| LIT | Size of a country’s literate population 15 years or over |
| POPU | Size of country by population |
| LFOR | Size of country’s labour force |
| PAUS | Patents in the US by residents of a given country |
| PATE | External patents by residents |
| PATR | Patents by a country’s residents |
| PATT | Patents by residents and non-residents in the country |
| PUB | Publication counts |
| CIT | Citation counts |
| PRO | Productivity |

| | |
|---|---|
| RICYT | Red Iberoamericana de lndicadores en Ciencia y Tecnologia |
| HAU | Historically Advanced Universities |
| HDU | Historically Disadvantaged Universities |
| HWU | Historically White Universities |
| HBU | Historically Black Universities |
| CSIR | Council of Scientific and Industrial Research (CSIR) |
| HSRC | Human Sciences Research Council |
| MRC | Medical Research Council |
| MINTEK | Mineral Technology Council |
| SABS | South African Bureau of Standards |
| GCS | Council for Geosciences |
| ARC | Agricultural Research Council |
| NRF | National Research Foundation |
| SAAO | South African Astronomical Observatory |
| HartRAO | Hartebeeshoek Radio Astronomy Observatory |

# 1. INTRODUCTION AND BACKGROUND

## 1.1. Introduction: Growth through Science and Technology

Michael Porter (1990:6) states that a nation's principal economic goal is to produce a high and rising standard of living for its citizens. The ability to do so depends on the productivity with which a nation's resources are deployed. Porter defines productivity as "the value of output by a unit of labour or capital." He argues that productivity is the prime determinant for a country's standard of living, as it determines the per capita income of a nation. In other words, by increasing the productivity of the citizens in a country, the per capita GDP will increase, from which economic growth should follow.

Technological change is seen as a key driver for growth in a country. Charles Edquist (1997:1) argues that it is almost universally accepted that technological change and other kinds of innovations are the most important sources of productivity growth and increased material welfare and that this has been the case for centuries.

Technological change has provided firms with the power to circumvent scarce factors via new products and processes. The use of materials, energy and other resource-based inputs has either been substantially reduced or synthetic substitutes have been developed.

Modern materials, such as engineering plastics, ceramics, carbon fibres and silicon, used in producing semiconductors, are cheap and ubiquitous, considerably reducing the importance of scarce factors at large. Automation and process innovations resulted in a reduction of the labour content within many industries, thereby rendering access to high technology more important than low local wages (Porter, 1990:14).

It will be shown in the next section that this argument also holds true for the South African economy, since it has became increasingly dependent on technology and technological progress. The section also explores the pivotal role that technological progress has played in South Africa's economic growth performance over the past decades.

## 1.2. The Role of Technological Change in the South African Economy

Fedderke (2002) investigated the nature and extent of changes in the underlying production structure of the South African economy by identifying the main sources of economic growth and any changes that might have occurred in their relative contributions/importance over time. He performed a simple accounting exercise to break down output growth into growth in capital, growth in labour and growth in technology or total factor productivity.

**Table 1-1: Contributions to Growth: 1970 – 2000 (%)**

| Period | Real GDP Growth | Sources of Growth | |
|---|---|---|---|
| | | ***Constant Returns to Scale*** | ***Decreasing Returns to Scale*** |

| | | Labour Growth | Capital Growth | Technology Growth | Technology Growth |
|---|---|---|---|---|---|
| 1970-1979 | 3.03 | 0.80 | 3.64 | -1.41 | -0.30 |
| 1980-1989 | 2.24 | 0.42 | 1.72 | 0.10 | 0.62 |
| 1990-1999 | 1.58 | -0.52 | 0.58 | 1.52 | 1.73 |

The above table indicates that the single strongest contributor to output growth during the course of the 1990s is a strong rise in technology. While output growth in the economy as a whole was driven by growth in factor inputs during the 1970s and 1980s, the 1990s saw a growing reliance on technological improvements and efficiency gains in the economy.

This phenomenon can in part be ascribed to the decline in formal sector employment in South Africa during the 1990s. Consequently, growth in labour inputs could not possibly have added to the growth in real output of the economy. As far as the declining contribution of capital is concerned, the growth performance of the South African economy can in turn be ascribed to the declining investment rate that South Africa has experienced.

Fedderke finds that the contribution of technological progress to South African growth in aggregate has been rising steadily since the 1970s, but that it has contributed a rising share to a declining growth rate in output.

The increased and substantial contribution of technology growth since the 1990s reflects the policy and institutional changes during that specific period. During the post-apartheid era, South Africa engaged in policies for social upliftment in support of education, health, crime and infrastructure. More importantly, South Africa also gained access to world markets and economies. International trade and investment offered important vehicles for technological spillover effects, while greater private sector participation in the economy increased the scope for technological innovation.

It can be concluded from the above section that science and technology indeed plays a pivotal role in the development and growth of the South African economy. Technological progress has become the engine of economic growth and a powerful tool to be used by economic policy makers to address the growth and employment problems of the South African economy effectively.

### 1.3. The Role of R&D in Technological Change

In the literature the importance of a country's ability to perform R&D as well as the role it plays in a country's ability to improve its competitive position is widely acknowledged and documented.

Chris Freeman (1978) introduced the concept of a National System of Innovation (NSI) to describe and interpret the performance of Japan, the economically most successful country of the post World War II period. Freeman defined the NSI as "the network of institutions of private and public sectors, whose activities and interactions initiate, import, modify, and diffuse new technologies". The systemic approach of innovation is based on the perception that innovations are ultimately brought about by the various components and the relations between them.

The innovation systems approach aims to identify the key components playing a central part in performing the system's functions. Freeman (1992:170) acknowledges the importance of R&D in formal scientific and technical organisations within the NSI. He believes that although R&D is not the only source of technical change, it is one of the foremost points of entry for new scientific development and the central focus for the development of new products and processes in most branches of industry.

R&D is also introduced as a form of organisational learning. Cohen and Levinthal (1989) argue that R&D plays a dual role within an economy. They assert that R&D not only generates new information, but also enhances the ability to assimilate and exploit existing information. The ease and character of learning in an industry influences and affects both the R&D spending and condition the appropriability and technology opportunity conditions in an industry. The cost of learning is borne from the development of a stock of knowledge, which constitutes absorptive capacity.

A significant benefit of R&D is its contribution to the current knowledge base. Cohen and Levinthal believe that since the long-term investment in developing an R&D capacity is substantial, it is not a trivial issue and is a matter of urgency that should be looked into (Cohen and Levinthal, 1989).

The above section concludes that R&D plays a crucial role in the NSI. Although not the sole driver of technological change, it certainly remains a pivotal one. R&D not only plays a key part in the development of innovative knowledge, it also enhances the ability to absorb knowledge and to keep up with technological change in the external environment.

Another key factor established in the above section is that the development of R&D requires a considerable investment in terms of time, funds and effort.

The following section provides a brief description of the development of the South African R&D system.

## 1.4. History of the South African R&D System

The use and development of new technology and science in South Africa has been an integral part of Africa in terms of both identity and culture. Archaeological discoveries dating back as far as the first Stone Age provide evidence of the success with which S&T has been employed on this continent (CENIS, 2000). These facts and artefacts testify to the technological abilities of the indigenous people of Africa as well as the central place that science and technology had in their lives.

The first formal documentation of scientific and technological activities in South Africa dates from the 18th century when the Cape colony attracted scientists from a bold young science born of the European Renaissance (CENIS, 2000).

### 1.4.1. Science for the sake of knowledge

During 1751 to 1880, scientific exploration in South Africa was an activity mainly conducted by travelling scholars. An example is Abbot de la Caille from the French academy of science who, apart from other important contributions, determined the position of nearly 10 000 stars classified in order of brightness and identified 42 nebulae (Marais, 1999: 174).

Another factor that spurred scientific exploration was the abundance of fauna and flora in the Cape colony. Since 1652, collections and examples were sent to Europe for further study. However, the foreign scientists' interest also extended beyond fauna and flora to include areas such as geomorphology and mineralogy (CENIS, 2000).

Given the dispute over ownership of the Cape colony between the English and the Dutch, many field notes were never published, resulting in a large amount of work being duplicated locally. Each change in military fortune resulted in the losing party destroying the knowledge thought to be of strategic importance (CENIS, 2000).

The English's final occupation of the Cape in 1810 was followed by the establishment of a number of public institutes and organisations, such as the Vaccine institute in Cape Town (1811), The Royal Observatory (1820) and The South African Museum (1825) (Naude & Braun, 1977:70).

Since 1830, private initiatives had spawned colleges such as the South African College at the Cape as well as colleges at Grahamstown, Bloemfontein and Stellenbosch. Many of these colleges gained university status after 1873. In 1873, the University of the Cape of Good Hope was opened. The period between 1906 and 1916 also saw the establishment of a number of colleges, including those at Pretoria, Natal and Fort Hare.

### 1.4.2. Industrialisation and 'science for practice'

The discovery of gold and diamonds in 1867 to 75 resulted in a large numbers of people agglomerating to search for precious materials. The 1886 gold rush to the Witwatersrand not only created the need for a better-developed mass food production as well as a rail and road system but also for a mechanism to cope with pressing shortages of, amongst others, wood and timber (CENIS, 2000). The vertical and horizontal value chains that consequently developed around the mines formed the basis for the modern economy (Kahn, 2004:1).

The novel circumstances also altered the face and grounds for operating science in South Africa. The mining enterprises' dire need for professionals, such as engineers, geologists, geophysicists, doctors and chemists, aggravated by the colony's inability to supply these resources, resulted in the necessary professionals being imported from Europe. This also resulted directly in science as a career becoming a reality. The last decade of the 19$^{th}$ century saw many professional societies being established to increase the standing of the numerous disciplines (CENIS, 2000:9).

The demands of the new system for more people, mass production of food supplies and importation of unchecked plant stock placed a lot of stress on the environment, which, in turn, led to a series of disasters, such as human and plant diseases as well as animal parasite attacks. The government turned to science for answers to these problems by hiring world-renowned specialists, who were later replaced by young scientists. Science was indeed employed successfully to solve many of these problems.

Following the successful development of a serum for rinderpest by Theiler (a French specialist from the Pasteur Institute in France), government gave permission that an institute aimed at developing and producing vaccines and sera against human and animal diseases be founded. Theiler's successes in controlling epidemics therefore resulted in government building the country's first Institute of Research, namely Onderstepoort, which opened in 1908.

Private initiative added a second important dimension to research performed locally. The mining industry noticed a high incidence of illness amongst employees, which impacted negatively on production. This problem led to the establishment of the second research institute in South Africa, the South African Institute for Medical Research (SAIMR), which was originally funded mainly by the mining sector to research occupational diseases.

Born from the necessity of production, South Africa took its first steps towards producing 'home-grown', applied research. From this, government was also pressurised for assistance in basic research activities.

### 1.4.3. The period between WWI and WWII (1920's -1930's)

As universities in South Africa grew, they started to show some interest in performing research in the paradigm of 'science for the sake of knowledge'. Research within these organisations tended to have no association with either social needs or the movement of science worldwide. During this period, academic university research remained within the realms of botany, entomology, zoology, human palaeontology and archaeology. Universities produced preciously little work of significance outside these fields.

Until the 1940s, the leading figures of fundamental science were however from institutions other than universities. During this period, the paradigm of 'science for doing' dominated the field by providing research scientists with better working conditions and facilities.

Factors promoting applied research in the inter-war period were even more prevalent. Following the Ministry of Mines' movement to an increasingly more scientific approach to geological surveying, a wealth of minerals was discovered and new mining companies were formed, thus enhancing the need for more engineers, scientists, geologists, experts in mechanics, etc.

The emergency of energy problems resulted in the Institute of Fuel Research being formed in 1932. This led to the exploitation of local oil and coal, but also to the establishment of an iron and steel industry to stimulate such a measure.

Other industries were also converted to science, for example the Natal sugar refiners, who established research facilities for the valorisation of by-products as well as entomology.

The Ministry of Agriculture was also convinced of the many merits associated with an involvement in science, resulting in, amongst others, the Departments of Agriculture being established at the Universities of Pretoria and Stellenbosch.

WWI revealed the weaknesses of an economy dependent on primary products. The Industries Advisory Board, established in 1916, under auspices of the Ministry of Mines and representatives of commerce and industry, appointed a Scientific and Technical committee and undertook to formulate an industrial development policy. This decree resulted in the creation of a foundation for funding university research.

H.J. van der Bijl was appointed as the Prime Minister of the Union of South Africa's Scientific Advisor. Van der Bijl developed a strategy to resolve research priorities, thereby ensuring South Africa's future independence in techno-scientific areas. Although the strategy achieved little more than gathering dust initially, van der Bijl eventually (at least partly) succeeded in accomplishing his plan as head of public companies ESKOM (responsible for electricity production, founded in 1923), ISCOR (Iron and Steel Corporation) and IDC (Industrial Development Corporation, founded in 1940).

### 1.4.4. The Nationalist ideology: strategic science

As WWII broke out, the South African economy had to substitute many of its imported products, including oil. The country also had to supply armies in Africa as well as the Middle East with items, ranging from vaccines to food.

During this period, South Africa was required to evolve manufacturing abilities for spare parts, i.e. aircraft, boats, etc., and to start manufacturing armaments such as rifles, bombs, armoured vehicles and precision equipment, e.g. RADAR. The search for minerals such as chromium, titanium, vanadium and uranium received a new boost. Industry was rushed into action. Capabilities within South Africa were tracked down and where unavailable, imported from Europe. The outbreak of WWII therefore resulted in South Africa experiencing its first industrial revolution, from which it would not revert back to a purely primary economy (CENIS, 200:23).

The South African Prime Minister, General Jan Smuts, a scholar and philosopher, appointed B. Schonland as scientific adviser to the Prime Minister. His major task was to formulate plans for establishing an organisation to advise the South African government on the best methods for developing the country's natural resources to the full and to co-ordinate scientific research in the national interest. Schonland's proposals adopted the Australian and Canadian research councils as the most appropriate models. In June 1945, the Scientific Research Council Act was passed. A few months later, on 5 October 1945, a state research laboratory was established, which today constitutes the Council for Scientific and Industrial Research (CSIR) (Marais, 1999:69).

In less than five years, the CSIR set up five national laboratories specialising in physics, chemistry, materials, telecommunications and industrial psychology. These laboratories were both well equipped and endowed with excellent personnel. The CSIR grew from only 70 employees in 1945 to 4 000 in 1970.

National programmes were created, entailing the co-operation of various institutes to participate in research over an extended period in a complex area of constant interest for the country. These programmes included Antarctic research projects, atmospheric physics and space physics, atomic energy and other forms of energy. Since 1980, these programmes included university research for public organisations such as ESCOM, SASOL, the Chamber of Mines, etc.

For a while, the CSIR continued to play the role of initiator for projects with strategic significance for the future. The following are examples of its research programmes:

- microelectronics, integrated circuit design, chemical process technologies, physics and metallurgy of electronic devices
- applied mathematics, computer science and industrial statistics; and
- nuclear physics, application of radioisotopes for medical treatment and diagnosis, construction of the cyclotron in 1955 replaced in 1977 by an accelerator, built and set into operation by the CSIR.

In 1952, the CSIR was placed under the Department of Economics' control. This led to the loss of the CSIR's inter-ministerial status and its capacity for arbitration. The president of the CSIR was also no longer automatically the Scientific Advisor to the Prime Minister.

Other research institutes slowly started to emerge independent from the CSIR. The following table (Marais, 1999:74) tracks the evolution of the other science councils. Marais stresses that although the establishment at first appears smooth and progressive, it was often a complex and highly politicised route.

**Table 1-2 Evolution of Science Councils in South Africa (Marais, 1999:74)**

| Council | Origin | Date | Location | Ministry |
|---|---|---|---|---|
| **CSIR** | N/A | 1945 | Pretoria | DTI |
| **SA Bureau of Standards** | CSIR | 1945/62 | Pretoria | DTI |
| **Atomic Energy Corp** | CSIR | 1948/59 | Pelindaba | Minerals & Energy |
| **C Minerals Technology** | D Mining | 1981 | Pretoria | Minerals & Energy |
| **Human Sciences RC** | Education | 1969 | Pretoria | ACST |
| **Medical Research C** | CSIR | 1969 | Bellville | Health |
| **Agricultural Research C** | Agricultural | 1992 | Pretoria | Agricultural |
| **Council for Geosciences** | Geological Surveys | 1992 | Pretoria | Minerals & Energy |
| **Foundation for Research Development** | CSIR | 1990 | Pretoria | ACST |

| | | | | |
|---|---|---|---|---|
| **National Research Foundation** | FRD/HSRC | 1999 | Pretoria | ACST |

Although South Africa lagged behind other commonwealth countries in terms of the establishment of science councils, the organisational space became densely populated since the 1960s (Marais, 1999:87). The 1960s and 1970s were characterised by tight government control of the science councils and the council presidents were all ministerial appointments. Government control over universities was less effective. The government thus found it easier to create ethnic universities and regain a degree of control over their governance (CENIS, 2000:32).

As the apartheid policy was institutionalised more rapidly, it led to the promulgation of the Extension of University Education Act in 1959. The act resulted in four new universities being established for students of specific population categories, namely the University Colleges of the North (Turf loop), Zululand, Western Cape and Durban-Westville. The Fort Hare Transfer Act restricted students attending this university to Xhosa-speaking Africans (CENIS, 2000:31).

During the early 1980s, five more universities with the same basic ideological framework were established. Race remained one of the main criteria determining access to higher education until the late 1980s. These universities, now referred to as Historically Black Universities (HBUs), focused primarily on vocational training on an undergraduate level. The proportion of students on postgraduate level was very small. Master degrees and doctorates awarded from these universities represented approximately 1% of the total number of all degrees and diplomas awarded. R&D expenditure by HBUs during 1991/1992 represented 7% of the national R&D expenditure of the university sector (Marais, 1999:80).

Technikons were established in 1978 along the same line as British polytechnics. These educational bodies emphasised skills training, which inhibited them from developing a research culture. Technikons were granted a research mandate in 1983 and degree-awarding status in 1993. This decree stimulated R&D activities in Technikons on the levels of policy development and postgraduate training. During the 1990s and 1980s, the FRD and HSRC started programmes for promoting R&D in these institutions (Marais, 1999:81).

### 1.4.5. The 1980s and early 1990s

Government adopted the system 'Framework Autonomy and Base Line Funding' for the management of the science councils in April 1988. A government subsidy was fixed to force councils to secure funding from clients in the public or private sectors. This system was enforced specifically to increase linkages between councils and industry (Kaplan, 1995:8). In this respect, implementation of the framework can be regarded as successful.

However, this decree held a number of negative consequences for research culture within the councils. The councils' research portfolios became increasingly more market driven, which resulted in a shift in focus from the socio-economic and development goals. Collaboration between institutes declined and competition became the order of the day. This shift towards a more market driven model came under fire (CENIS, 2000: 35).

The political situation in South Africa underwent a significant change in the 1980s and early 1990s. The Mass Democratic Movement began playing a more significant role in S&T issues, while African National Congress (ANC) spokespersons and bodies called for a change in the system (CENIS, 2000: 35).

The elections on 27 April 1994 were a watershed event. The new government reviewed public policies and developed new policy imperatives, thereby setting the country on a course where all citizens could benefit from and contribute to economic growth and social development. The main priorities of the new South African government were focused on the socio-economic development of previously disadvantaged individuals.

## 1.5. Major Developments in the South African S&T System after 1994

### 1.5.1. The macro policy context

The new government launched a Reconstruction and Development Programme (RDP) as a policy framework for integrated and coherent social and economic progress. Published in 1994, the White Paper on Reconstruction and Development aimed to build a democratic, non-racial and non-sexist future for South Africa (GOV, 1994).

In late 1995, government adopted the principal blueprint for action aimed at growth and development, namely the Growth and Development Strategy (GDS). This strategy, an elaboration on the RDP, was built on the following six pillars (DACST, 1996: 73):

- investing in people as the productive and creative core of the economy
- creating employment on a large scale while building a powerful, internationally competitive South African and Southern African economy
- using enhanced investment in household and economic infrastructure both to facilitate growth as well as improve the quality of life of the poor
- a national crime prevention and security strategy to protect the livelihood of our people to secure the wealth of the country and promote investment
- transforming government into an efficient and responsive instrument of delivery and empowerment, able to serve all South Africans while directing government resources primarily to meet the needs of the poor majority; and
- using a system of welfare ‘safety nets’ to draw the poorest and most vulnerable groups progressively into the mainstream of the economy and society.

As the goals set in the RDP failed to deliver on its promises, the RDP office was closed on June 1996.

Despite its previous commitment to socialism, the new ANC government adopted the Washington consensus and implemented a structural adjustment programme (Kahn, 2004). On 14 June 1996, the government published the policy document on growth, employment and redistribution strategy. This strategy differed from the RDP in its clear commitment to a neo-liberal, macro-economic policy. The core elements of the integrated strategy are (Department of Finance, 1996):

- a renewed focus on budget reform to strengthen the redistributive thrust of expenditure
- a faster fiscal deficit reduction programme to contain debt service obligations, counter inflation and free resources for investment
- an exchange rate policy to stabilise the real effective rate at a competitive level
- consistent monetary policy to prevent a resurgence of inflation
- a further step in the gradual relaxation of exchange controls
- a reduction in tariffs to contain input prices and facilitate industrial restructuring, compensating partially for the exchange rate depreciation
- tax incentives to stimulate new investment in competitive and labour absorbing projects
- speeding up the restructuring of state assets to optimise investment resources
- an expansionary infrastructure programme to address service deficiencies and backlogs
- an appropriately structured flexibility within the collective bargaining system
- a strengthened levy system to fund training on a scale commensurate with needs
- an expansion of trade and investment flows in Southern Africa; and
- a commitment to the implementation of stable and coordinated policies.

Together, the governments of 1994 and 1999 produced more than 800 acts of parliament to drive a modernisation agenda. These acts included, amongst others, the Labour Relations Act (1996), the Public Finance Management Act (1999) and the Employment Equity Act (1998). These three items of legislation were aimed specifically at improving labour relations and institutional governance. The Higher Education Act (1999) provides the framework for the re-organisation of higher education through a series of institutional mergers. In theory, the Immigration Act (2002) provides a mechanism to address scarce skills through foreign recruitment, but in practice erects administrative barriers that are likely to impede inward flows (Kahn, 2004:10).

The following section discusses the science and technology policy in South Africa against the background of the macro-policies discussed in this section.

### 1.5.2. Science and technology policy

Under the previous government, management of S&T was divided. The responsibility for science rested with the Department of Education, while the Department of Trade and Industry was responsible for technology. Previously, the key source of advice to government on science policy was the Scientific Advisory Council, located in the Department of National Education. The council was however criticised for a lack of transparency, its composition of its membership and a limited oversight of the system.

Following the 1994 democratic elections, the Department of Arts, Culture, Science and Technology (DACST) took over the management responsibility. The creation of the Ministry and Department of Art, Culture, Science and Technology in 1994 was a step towards creating a vehicle for government to focus its role in developing a science and technology system that would respond to the government’s priorities.

The South African government published a consolidated policy entitled The White Paper on Science and Technology: Preparing for the 21st century in 1996 (DACST, 1996). The policy was designed specifically to reinforce the pillars of the GDS. The White Paper acknowledged the importance and the role that technological innovation will play in the further development of the South African economy (DACST, 1996: 9) by stating:

"*The development and application of science and technology within a national system of innovation (NSI) in South Africa will be central to the success of the Growth and Development Strategy (GDS) of the Government as it seeks to address the needs of all South Africans. In keeping with a variety of political, constitutional, social, and economic changes introduced by the government, the NSI as an enabling framework for science and technology is intended to support the six pillars of the Growth and Development Strategy.*

*The stimulation of a national system of innovation will be central to the empowerment of all South Africans as they seek to achieve social, political, economic, and environmental goals. The development of innovative ideas, products, institutional arrangements, and processes will enable the country to address more effectively the needs and aspirations of its citizens. This is particularly important within the context of the demands of global economic competitiveness, sustainable development and equity considerations related to the legacies of our past. A well-managed and properly functioning national system of innovation will make it possible for all South Africans to enjoy the economic, socio-political and intellectual benefits of science and technology*." (DACST, 1996:8)

In this policy space, the White Paper on Science and Technology (DACST, 1996) approved by Cabinet in 1996, established a policy framework for science and technology in South Africa based on the concept of an NSI.

The issues the White Paper addressed as systemic failures requiring concerted national action were spelt out as follows (OECD, 2000:1):

- a fragmented and inadequately co-ordinated science and technology system
- the erosion of innovative capacity
- poor knowledge and technology flows from the science base into industry
- poor networking both within the region and in the global context
- inefficiencies and poor levels of investment in research and development
- imbalances created by past policies and actions; and
- a poor competitive position within the global environment.

Policy development took cognisance of the nature and strength of the institutions/organisations within the NSI, their relationships with one another, their importance to the economy and South African society in particular and the implications and impact of various other government policies. The focus sought a science and technology alignment with new thrusts in areas such as education, communication, labour, health, trade and the environment (OECD, 2000:1). The new policy had the following objectives:

- broaden the scope of policy from S&T to innovation
- recognise R&D as crucial to growth and to the improvement of quality of life
- supports the co-ordination and non-duplication of structures
- pursues the levelling of historical inequalities and human capacity building
- provides core funding in terms of a three-year cycle through the Medium-term Expenditure Framework (MTEF) for capacity building and maintenance in R&D and related activities, while R&D services for clients are managed on a commercial basis with full cost recovery; and
- requires regular reviews of government Science, Engineering, and Technology Institutions (SETS) (DACST, 2002:6).

The following section describes the research topic and problem dealt with in this research project.

## 1.6. Research Problem

The previous sections clearly illustrated that South Africa's R&D system enjoyed a steady development over a number of centuries. Over time, crucial policy decisions regarding the investment of resources in an R&D system are made. These decisions have long-term consequences on the system and have a direct impact on the system's current and future ability to function and produce R&D output.

There exist some concern regarding the sustainability of the production of R&D output and R&D capacity in South Africa. Recent trends indicated the following evidence of disinvestments and decay of South Africa's R&D capacity:

- R&D expenditure in SA decreased from 1.2% of GDP in 1987 to 0.76% in 2001. This is rather low when compared to the OECD average of 2.15% (DACST, July 2002)
- evidence shows that South Africa's position as a knowledge creator is declining. In 1990, South Africa created 0.8% of the world's scientific output, while creating only 0,5% in 2002 (DACST, July 2002); and
- more alarming evidence that South Africa has an ageing R&D workforce. A lack of rejuvenation in the human resource base resulted in researchers in the age group 30 - 49 decreasing from 77% in 1990 to 45% in 1998 ((NACI, 2002), (Boshoff, 2003)).

Questions arise concerning the detrimental effects these trends could have on South Africa's ability to generate R&D output. As problems are addressed insufficiently and the system is allowed to decay, the costs of rebuilding the system might increase even further. A research question is posed:

*What is the delayed effect of R&D investment or the lack thereof on the South African NSI's ability to produce R&D output?*

The main research objective is to develop a computer simulation program of R&D performance and the creation of R&D output in the NSI. This model will in turn produce a tool to be used for policy testing, what-if scenario testing or policy optimisation.

The purpose of the model is to simulate R&D output generated in the South African system of innovation and to model and explain the effect the presence/lack of long-term investment in R&D and R&D resources could have on the system's ability to produce R&D output.

Examples of scenario tests on the higher education sector model are:

- how can a constant investment in the South African higher education system affect its ability to produce R&D output and absorb knowledge?
- how can an increasing/decreasing level of investment in the South African higher education system affect its ability to produce R&D output and absorb knowledge?
- how can the introduction of dedicated researchers in the system (science chairs) influence system performance?
- how can a delayed reaction to the decay of R&D capacity influence the system and the cost to rebuild lost capacity?
- how can the introduction of better time management skills in academic and research personnel influence system performance?

Examples of scenario tests on the public sector system model are:

- how can a constant investment in the South African public sector affect its ability to produce R&D output and absorb knowledge?
- how can an increasing/decreasing level of investment in the South African public sector affect its ability to produce R&D output and absorb knowledge?
- how can a movement away from the framework autonomy policy influence the system?

Examples of scenario tests on the private sector system model are:

- how can a constant investment in the South African private sector affect its ability to produce R&D output and absorb knowledge?
- how can an increasing/decreasing level of investment in the South African private sector affect its ability to produce R&D output and absorb knowledge?
- how can the introduction of fiscal incentives influence R&D expenditure and the ability to produce R&D output and absorb knowledge?

The following section explores the rationale behind the research project and states the motivation for having a model capable of displaying the dynamic properties of the South African R&D system.

## 1.7. Rationale for the Study

The rationale behind this study is that adopting a computer simulation model of a dynamic system as an analytical tool will expose complex system behaviour. This will result in a better understanding of the system as a whole. Through its effectiveness in capturing and exposing the state of the system, the model improves on more conventional methods for evaluating policy effectiveness (Moles & O'Regan, 2003).

In developing this model and by using the corresponding simulation programme, decision-makers in government and industry are provided with a tool to analyse policy alternatives. The model will provide a better understanding of the interrelationships between different elements of the NSI, in particular those interacting as funders and performers of R&D. This model will also aid decision makers in enhancing the efficiency of addressing problem areas within the South African R&D system.

## 1.8. Expected Contributions

Very little has been done in the field of creating dynamic models of NSI's. Carlsson et al (2002:236) states that the empirical analysis of studies carried out on NSI are mainly on static data. Many studies tend to be descriptive and consequently fail to capture the system's dynamic behaviour. This complicates the comparison of nations' relative positions over a period of time. According to Carlsson, there is nothing preventing a more dynamic analysis. At present, none of the descriptions of the South African NSI adequately explains either causal relationships or the dynamic behaviour of the South African R&D system and resulting R&D outputs.

This research project uses the system dynamic methodology's ability to model complex dynamic systems. The research will contribute to the system dynamics body of knowledge by illustrating the use of the system dynamics methodology and computer simulation for planning and managing R&D investments within the South African R&D system.

The contribution made by this thesis to the body of knowledge is that the development of a system dynamic model will result in the establishment of a dynamic hypothesis of the development of new knowledge through R&D in an R&D performing sector. The dynamic hypothesis will in turn lead to a method for modelling the effect of R&D investment on the development of an R&D capacity, i.e. the system's ability to absorbed knowledge and produce R&D output. The above is essentially a dynamic description of the process around creating and absorbing knowledge through R&D activities.

The dynamic hypothesis was tested and validated by applying the conceptual model to the South African R&D system. This application can also be classified as a contribution to the state of knowledge regarding R&D activities within the South African R&D system. The conceptual model was applied to the following three R&D sectors in South Africa: namely:

- the Higher Education System (HES), i.e. universities, universities of technology and technikons

- the public sector, i.e. science councils, state departments and museums; and
- the private sector, i.e. South African companies.

This thesis illustrates the model being applied to test different scenarios. A number of conclusions are consequently drawn regarding the South African R&D system and its ability to produce R&D output.

The system dynamics model developed in this research project is intended to be used as a policy tool for government or policy makers to aid them in the development of S&T policy.

### 1.9. Thesis Outline

The following is a graphical representation of the thesis structure.

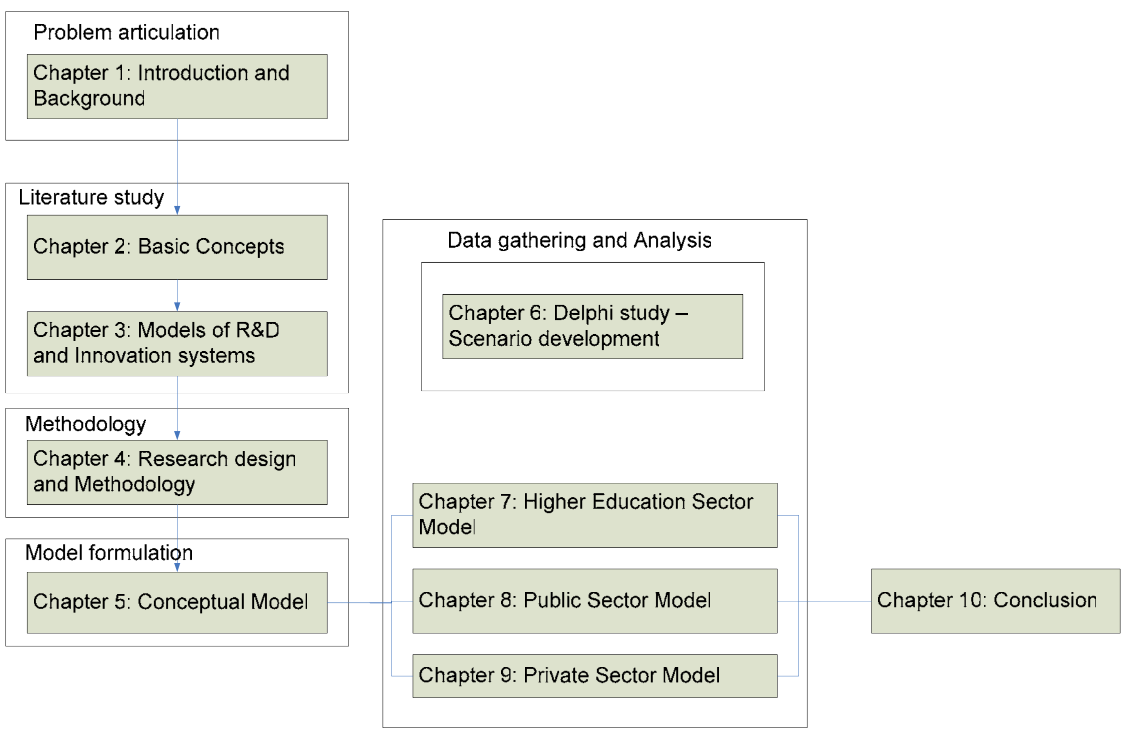



**Figure 1-1 Graphical representation of the thesis structure**

#### 1.9.1. Basic concepts of R&D and innovation systems

**Chapter 2** covers a comprehensive literature overview of the most authoritative scholarship available at present. The chapter comprises both a discussion as well as a critical analysis on the evolution of the innovation concepts from the first linear models to the current NSI framework.

**Chapter 3** documents and critically analyses models developed for evaluating R&D and innovation systems. This includes quantitative and qualitative models of R&D, innovation and other related concepts. A section is also allocated to discuss previous attempts to develop system models of R&D and innovation. The chapter finally provides examples of system dynamics models created for single R&D project models as well as models that have been developed for R&D and innovation on a more aggregate level.

#### 1.9.2. Research design and methodology

**Chapter 4** comprises a presentation of the project's research design. The chapter also includes a discussion on the system dynamics methodology and explains its suitability for the problem at hand.

#### 1.9.3. The conceptual model

**Chapter 5** focuses on the development of a conceptual system dynamics model for the South African system of innovation. The knowledge obtained during the literature review enables an identification of the major elements necessary to represent the system's relevant aspects. These elements establish the structure of the model, while causal relationships and feedback loops between elements are conceptualised.

#### 1.9.4. Data Gathering and Analysis

**Chapter 6** documents the research project's primary data gathering phase. This includes a detailed discussion on the questionnaires and responses received from a group of experts participating in the Delphi study. Conclusions drawn from the Delphi study is used to develop a selection of scenario tests, which are run on the system models developed in Chapters 7 to 9.

**Chapters 7** to **9** document the process of applying the dynamic hypothesis to the higher education sector, public sector and private sector in South Africa. The chapters also discuss the secondary data gathering process and document the data sources. The model-testing phase and simulation runs are also discussed. Each model is discussed separately in the following chapters:

**Chapter 7: Higher education sector model**

**Chapter 8: Public sector model**

**Chapter 9: Private sector model**

#### 1.9.5. Summary and conclusions

**Chapter 10** highlights the contributions made to the body of knowledge in this research project by discussing the areas in which the model has contributed to a better understanding of R&D in the South African system of innovation. Based on the outcome of the scenario tests on the models, certain recommendations are made regarding R&D policy in South Africa. Finally, a section of chapter 10 is allocated towards self-assessment and lessons learnt from this project.

# 2 BASIC CONCEPTS OF R&D AND INNOVATION SYSTEMS

## 2.1 Purpose and Outline of the Chapter

This chapter documents a comprehensive literature study that represents the most authoritative material available at present in the field of innovation studies, especially within the NSI framework. This chapter provides a more detailed overview of the key concepts and frameworks used in the model developed in this research project. Various authors' theories and frameworks are discussed and critically analysed.

## 2.2 The Concept of Innovation

The innovation process cannot always be restricted to technical innovations. Schumpeter conceived the innovation process in a broad way and derived his definition of innovation by means of the production function (1939: 87):

"… this function describes the way in which quantity of product varies if quantities of factors vary".

Schumpeter defines innovation as the set-up of a new production function. In doing so, he includes a new commodity as well as new organisations. Schumpeter's (1934) definition of innovation includes the following five types of innovation:

- new or improved products
- production techniques
- organisational structures
- discovery of new markets; and
- use of new input factors.

Each of these forms of innovation possesses the potential of increasing productivity and therefore the competitiveness of a nation (Porter, 1990).

Throughout the innovation literature, authors provide a number of different definitions of innovation (Edquist, 1997). The following instances serve as examples:

- although referring specifically to technological innovations in the NSI, Nelson and Rosenberg (1993: 4-5) defines the concept of innovation quite broadly by including not only the first introduction of a new product to the market but also its diffusion
- Carlsson and Stankiewitz (1992) focus mainly on the 'technological systems' approach, i.e. the role of a technological system of innovation to initiate, diffuse and modify technology. This concept of innovation also include process as well as product technology; and
- Lundvall includes 'new forms of organisations' and 'institutional innovations' in his definition of innovation (Lundval, 1992:8, 9).

Edquist (1997:9-10) states that when a system of innovation approach is followed, authors focus mainly on technological innovation and are consequently interested in organisational and institutional change.

This section documents an overview of the concept of innovation within a systems framework. It should be noted that innovation has not always been viewed as a complex systemic process and that the understanding of the concept evolved over a period of time. The following section provides a brief overview of the evolution of the innovation concept.

### 2.2.1 The linear model of innovation

The 1960s saw the development the linear model of innovation, a concept that led to much discussion. This model of innovation states that the innovation process starts with the onset of basic research. The model depicts a system in which the development of new technologies follows a clear-cut time sequence that originates in research, involves a phase of product development and leads to production and commercialisation (OECD, 1994b). According to this model, the innovation path exists by being pushed by advances in science or pulled by needs of markets.

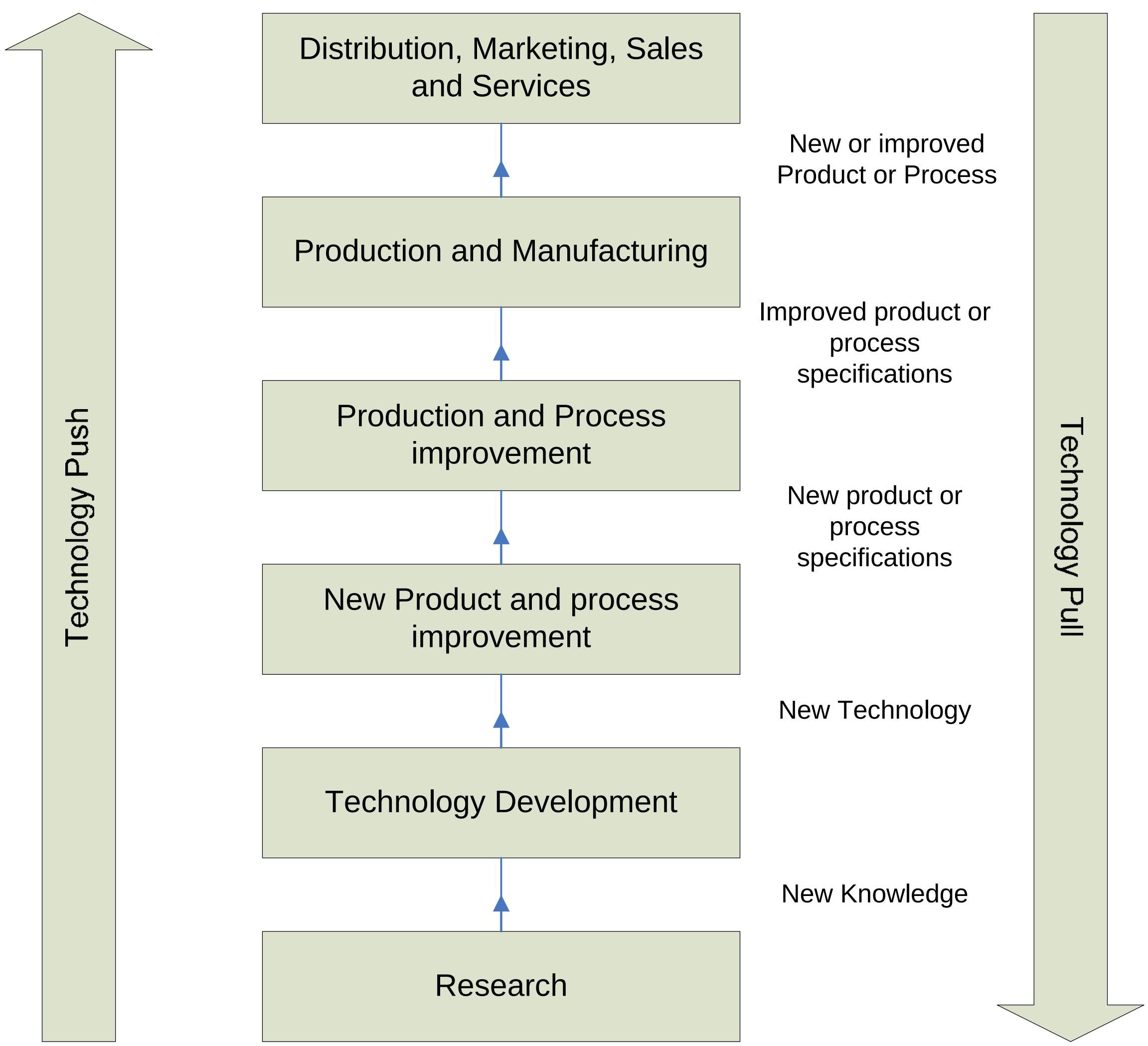


**Figure 2-1: The Linear Model of Innovation**

During the majority of the 1970s, the merits of both the science-push as well as the market-pull models were discussed. Market-pull models were criticised for its simplistic use of the market as a causal mechanism, whereas the science-push model was rejected for its failure to acknowledge the role that the market plays. Both these models were criticised for failing to acknowledge the complex interactions between involved groups (Rogers, June 1998:24).

### 2.2.2 The chain-linked model of innovation

The chain-linked model of innovation was essentially an improvement on the linear model in that it acknowledged interactiveness and feedback between stages. This model recognises that although innovation can draw on existing knowledge, it could also lead to the creation of new knowledge.

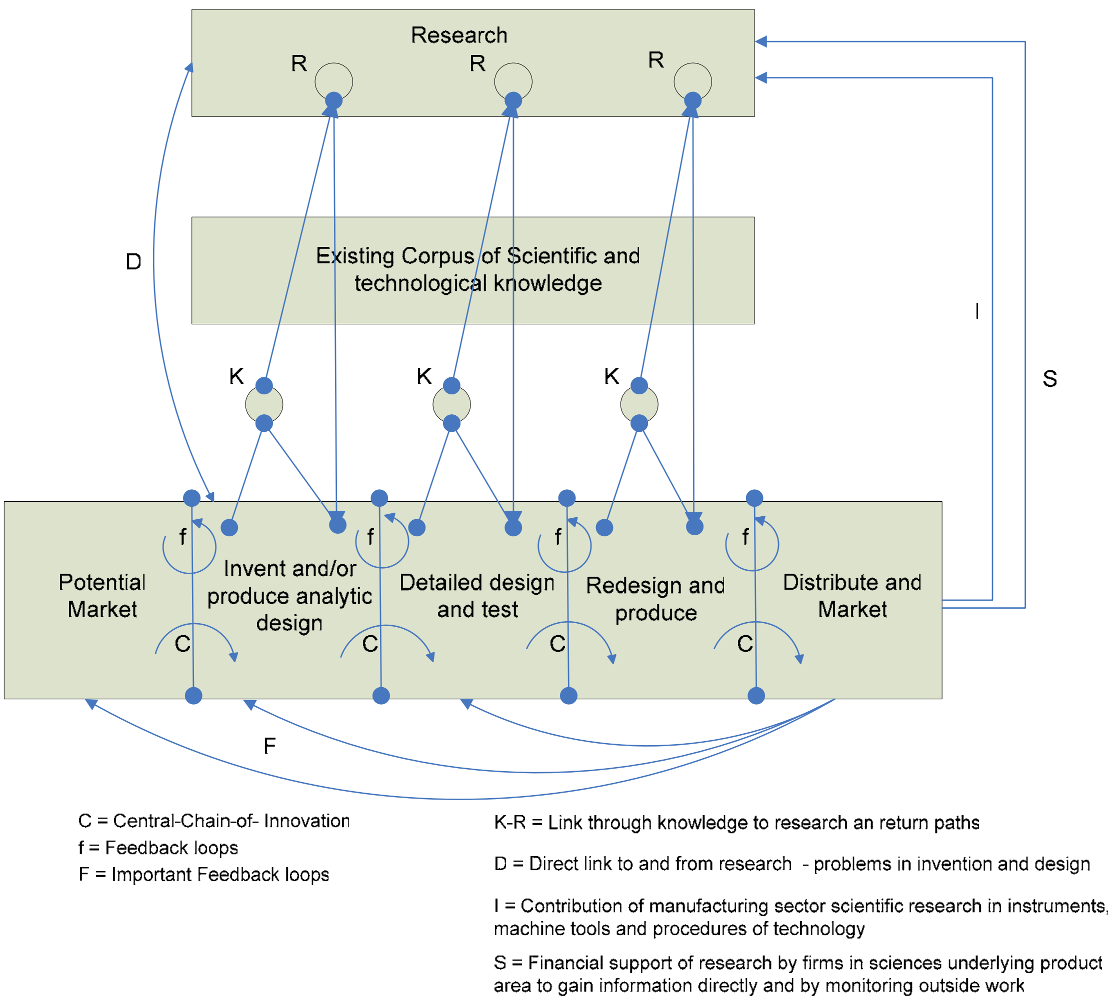



**Figure 2-2: The Chain-linked Model (Kline and Rosenberg, 1986)**

The chain-link model depicted in Figure 2-2 conceptualises innovation in terms of interaction between market opportunities and the firm's knowledge base and capabilities. Each broad function involves a number of sub-processes with highly uncertain outcomes. Accordingly, there is no simple progression, which often necessitates going back to earlier stages to overcome difficulties in development. This signifies feedback between all parts of the process.  A key element in determining the success of an innovation project is the extent to which firms manage to maintain effective links between the phases of the innovation process.  The model emphasises, for instance, the central importance of continuous interaction between marketing and the invention/design stages.

The chain-link model views research not as a source of inventive ideas but as a form of problem solving to be called upon at any point. When problems arise in the innovation process, as they are bound to do, a firm draws on its knowledge base at that particular time, which comprises earlier research findings as well as technical and practical experience. The research system takes up the difficulties that cannot be settled with the existing knowledge base, and so extends it if successful (OECD, 1996:25).

Accordingly, the chain-link approach does not view research simply as the work of discovery that precedes innovation. Research is a complex and internally differentiated activity, which is an adjunct as opposed to a precondition to innovation. The above is in line with the results gained from studies of innovative behaviour, which indicated that innovations rarely result from research activities alone (OECD, 2002d).

### 2.2.3 Summary

This thesis centres on the concept of R&D from an NSI perspective. This section discusses two earlier models of innovation, both of which acknowledge the role of R&D in the innovation process.

The first model, i.e. the linear model of innovation, describes the process of innovation as a linear process originating with the creation of new knowledge, i.e. research.  This is an extremely simplistic view and fails to acknowledge the complex feedback loops and dynamics involved in innovation and the R&D processes.

The second model, i.e. the chain-linked model of innovation, acknowledges the feedback loops, the more complex nature of innovation and the role of R&D as an adjunct rather than a precondition to innovation.

The above clearly indicates that R&D has been acknowledged as integral in the innovation process even in the very first models of innovation. The concept has since evolved from viewing R&D as the entry point of innovation to acknowledging it as a problem-solving device throughout the entire innovation process. The latter approach also implies that R&D is not the only entry point to innovation.

The most recent framework aimed at explaining the inherent complexity of innovation is the systems view.  Before explaining the system of innovation concept in more detail, attention is given to the system concept in general.

## 2.3 The System Concept

Interest in systems originates from the need to understand dynamic behaviour. The focus lies in the interactions within the system that ultimately produce growth, fluctuation and change (Forrester, 1974:4-1). The following section comprises a discussion on the definition, classification and structure of a system.

Forrester (1974, 1-1) defines a system as "a grouping of parts that operate together for a common purpose".

Blanchard and Fabrycky's reasoning aimed at defining a system was documented in the book entitled Systems Engineering an Analysis, (Blanchard and Fabrycky, 1998:2). They state that a system is an assemblage or combination of elements or parts forming a complex or unitary whole. A set of items, facts, methods or procedures can only qualify as a system if the group as a whole has functional relationships between elements, unity and a useful purpose.

Blanchard and Fabrycky (1998:2) ultimately define the systems concept as follows: "A system is a set of interrelated components working together toward some common objective or purpose."

According to Blanchard and Fabrycky (1998:2), systems are made up of components, relationships and attributes. These constituents are discussed below:

- *components* are the operating parts of the system and consist of input, process and output. Each system component may assume a variety of values to describe a system state as determined by a control action and one or more restrictions
- *attributes* are the properties or discernable manifestations of the components of a system. These attributes characterise the system; and
- *relationships* are the links between components and attributes.

Following their definitions of a system, Forrester as well as Blanchard and Fabrycky also expressed some thoughts on defining system boundaries, i.e. making a decision on which components to include in the system.

### 2.3.1 The System Boundary

Blanchard and Fabrycky (1998:2-3) assign the following properties to the set of components of a system:

- the properties and behaviour of each component of the set affects the properties and behaviour of the set as a whole
- the properties and behaviour of each component of the set depends on the properties and behaviour of at least one other component in the set; and
- each possible subset of components has the two properties listed previously, i.e. the components cannot be divided into independent subsets.

Both the definition of a system as well as the properties listed above implies that a system must have behaviour that is not exhibited by any of its subsets. Blanchard and Fabrycky (1998:2) believe that although the components of a system qualify as systems themselves, each system forms part of an even bigger system in the hierarchy.

It is therefore imperative to define the precise system under consideration by specifying its limits, boundaries or scope. Everything outside the boundaries is considered to be the environment.

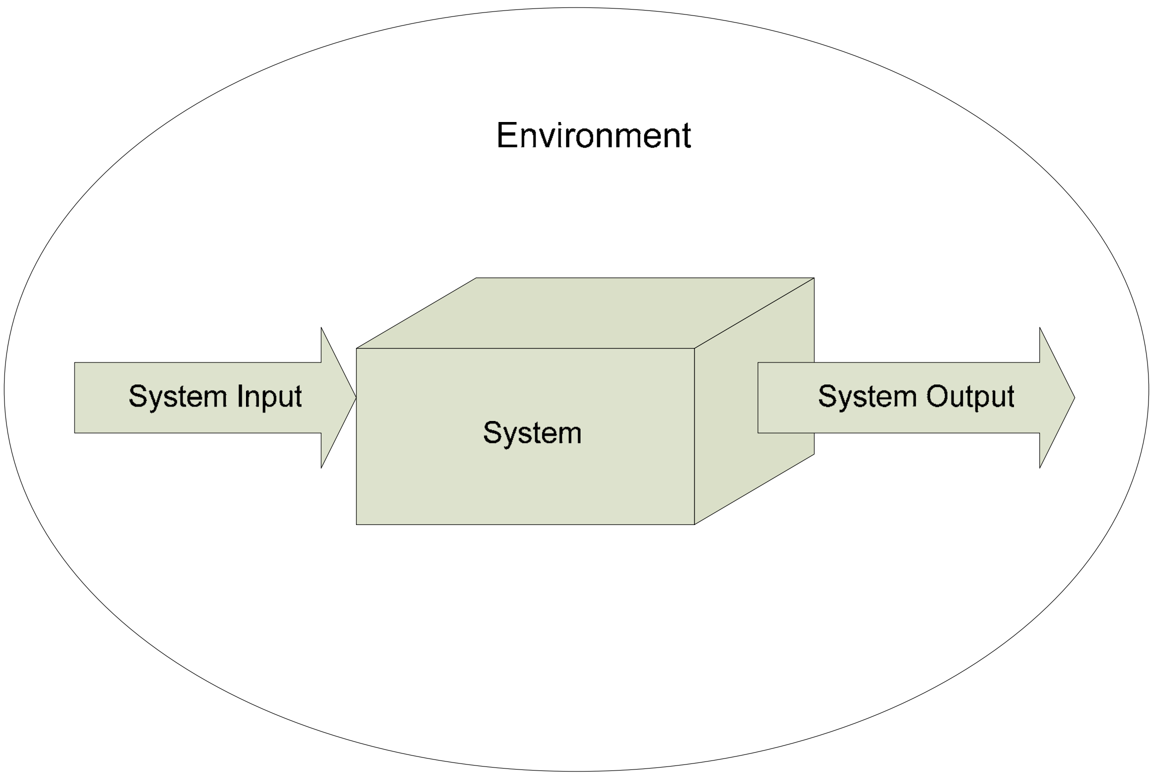



**Figure 2-3: The System Interacting with its Environment**

Blanchard and Fabrycky (1998:3) state that no system can function in complete isolation from its environment. Materials, energy and information often pass through boundaries as inputs to the system. The reverse is however also true: materials, energy and information pass through the system to the environment, which can also be referred to as output.
Figure 2-3 visually depicts the interaction between a system and its environment. Blanchard and Fabrycky's (1998:3) definition of a total system is: "The total system, at whatever level in the hierarchy, consists of all components, attributes and relationships needed to accomplish an objective."

Forrester (1974:4-2) illustrates similar views on defining the system boundary by stating that the specific behaviour of a system must be produced by a combination of interacting components. These components lie within a boundary that defines and encloses the system. Forrester (1974:4-2) defines the boundary of a system as the "smallest number of components within which the dynamic behaviour understudy is generated".

Forrester also acknowledges that structure organises in many layers of hierarchy and recognises the existence of sub-structures within every structure.

### 2.3.2 Classification of Systems

In an attempt to increase understanding, Blanchard and Fabrycky (1998:4-7) classify systems according to the following descriptions:

- *natural and man-made systems*: natural systems are those that result from natural processes, while man-made systems require some form of human intervention through components, attributes and relationships
- *physical and conceptual systems*: physical systems manifest in physical form, comprising real components, while conceptual systems represent attributes of components, e.g. ideas, plans and concepts
- *static and dynamic systems*: static systems have one structure without activity, e.g. a bridge, while dynamic systems combine structural components with activity, e.g. a school consists of buildings, students, teachers, books, etc.; and
- *closed and open systems*: a closed system does not interact with its environment. The environment simply provides the context for the system. An open system allows information, energy and matter to cross its boundaries. Open systems therefore interact with their environment, e.g. plants and business organisations.

Forrester (1974:1-5) distinguishes between two types of systems:

- *open systems* are characterised by outputs responding to input, where the outputs are isolated from and have no influence on the inputs. Past action has no effect on future action. Open systems neither observe nor act on their own performance; and
- *feedback systems (closed systems)* are influenced by their past behaviour. Such systems have closed loop structures that return results from the system's past actions to control future action:
  - positive feedback systems generate growth processes wherein action builds a result that generates still greater action, e.g. bacteria multiply to produce more bacteria, which, in turn, increases the rate at which new bacteria is generated; and
  - negative feedback systems seek a goal and responds as a consequence of failing to achieve the goal, e.g. a watch and its owner form a negative feedback loop when the watch is compared to the correct time and consequently adjusted to eliminate errors.

### 2.3.3 Structure of Systems

Blanchard and Fabrycky believes that understanding and defining the objective of a system is integral when analysing a system (Blanchard and Fabrycky, 1998:2): "The objective or purpose of a system must be explicitly defined and understood so that the system components may be selected to provide the desired output for each given set of inputs. Once defined, the objective or purpose makes it possible to establish a measure of effectiveness to indicate how well the system performs. Establishing the purpose of a human-made system and defining its measure of effectiveness is often a challenging task."

The purposeful action of a system is the function of a system. Where the function of a specific system is to alter material, energy or information, such a system will use inputs, processes and outputs. Such systems are composed of structural components, operating components and flow components (Blanchard and Fabrycky, 1998:2). These types of components are better defined as:

- *structural components*: the static parts of the system
- *operating components*: the parts performing the processing; and
- *flow components:* materials, energy and information being altered.

Forrester (1974:4-1) organises a system in the following hierarchy of major and subordinate components. The closed system that generates behaviour is created within a boundary and is independent of outside inputs:

- feedback loops as the basic element from which systems are assembled
- rates (or policies) as the other fundamental variable within a feedback loop
    - the goal as one component of a rate
    - the condition against which the goal is compared
    - the discrepancy between goal and apparent condition; and
    - action resulting from the discrepancy.

This above section explored the systems concept and explained the various system constituents, i.e. components, relationships and attributes.

### 2.3.4 Summary

The discussion of the systems concept is extremely insightful for the purpose of this thesis. It can be concluded that the challenge of defining a system lies in the formulation of the purpose of the system. Once the purpose is formulated, it becomes much easier to measure the system's effectiveness, or in other words, how well the systems transform input into output.

A thorough understanding of the purpose of a system also simplifies the process of selecting the main components. The modeller should select elements in the system that contribute to that system's behaviour.

Also very insightful to the purpose of the thesis is that all systems form part of a larger system. A decision regarding the system boundary as well as the aggregation level of the model is therefore necessary.

The following section focuses on introducing the system of innovation approach and discusses the differing views that various authors have on the components, relationships and attributes of the system.

## 2.4 Systems of Innovation

Chris Freeman was the first author to introduce the systems of innovation approach. He introduced the concept of a NSI to describe and interpret the performance of Japan, the country that was economically the most successful in the post World War II period. Freeman (1987) defined the NSI as "the network of institutions of private and public sectors, whose activities and interactions initiate, import, modify, and diffuse new technologies".

The systemic approach of innovation is based on the perception that innovations are ultimately brought about by the various components and the relations between them.

The innovation systems approach aims to identify the key components playing a central part in performing the system's functions. Before analysing the NSI concept in more detail, the reasons, merits and problems of analysing systems of innovation on a national level is discussed in the following section.

### 2.4.1 The analysis of innovation on the national level

The majority of innovation systems research is defined on a geographic scale. Although the national level proved predominant in the past, research has since been performed on regional and local level.

A number of researchers have argued against referring to systems of innovation on a national level. Lundvall (1992:3) disputes the use of studying innovation systems on a national level, whereas Nelson and Rosenberg (1993: 5) argued in favour of a sectoral approach. Pavitt's (1984) research focussed on innovative firm behaviour and functions as well as qualities and sources of technologies, consequently pursuing the development of a sectoral taxonomy of technological development as opposed to a geographical approach. Howells (1999: 67) suggested that regional systems of innovation could provide an additional layer to the NSI approach. He believes that geographical distance, accessibility, agglomeration and the presence of externalities provide a powerful influence on knowledge flows, learning and innovation.

Bo Carlsson and his team developed the 'technological system' approach within the framework of a research project on Sweden's technological systems and future development potential. This approach describes technology systems in different technology fields. Carlsson et all (1992: 49) argues that whereas the nation has natural boundaries, many technological systems co-exist. According to Carlsson, the size of a technological system depends on the technology and market requirements, various agents' capabilities as well as the degree of interdependence among agents. Technological systems can therefore be local, regional, national or international.

Strong arguments in favour of referring to systems of innovation on a national level also exist. Nelson's case studies (Nelson, 1993) conclude that differences on a national level exist in language, culture, standard of living, lifestyle, consumption patterns and the size of public sector. Public policies are designed on national level, which highlights the influence that politics and policy ultimately have on innovation processes.

Arguments both for and against analysing innovation on a national level can therefore be presented with a certain amount of conviction. Since the main objective of the model building study is the development of a policy tool for government officials to formulate national R&D policies, the national level approach is chosen. As Lundvall (1992, 3) points out that although globalisation and regionalisation might be interpreted to weaken the coherence and relevance of a national system, studying innovation on a national level will highlight the role and workings of a NSI.

The above arguments indicate that the national systems approach still plays an integral part in supporting and directing processes of innovation as well as learning. The national systems approach therefore remains relevant for the purpose of this study.

The decision to analyse the NSI on a national level also directs the system boundary definition for the model building study.

### 2.4.2 Components of systems of innovation

Authors tend to use the terms 'organisation' and 'institution' rather inconsistently in the literature analysed (Balzat, 2002; Edquist, 1997). The term 'institution' is used to refer to both organisations as well as institutions. As this study distinguishes between these terms, a proper definition of 'organisation' and 'institution' is necessary. The definitions provided by North (1994) are adapted for the purpose of this study.

Organisations comprise groups of individuals bound together by some common purpose to achieve certain objectives. Organisations include political bodies, e.g. political parties, the senate, a city council and regulatory bodies, economic bodies, e.g. firms, trade unions, family farms and co-operatives, social bodies, e.g. churches, clubs, athletic societies, etc. and educational bodies, e.g. schools, universities and vocational training centres.

Institutions are the humanly devised constraints that structure human interaction. These include formal constraint, e.g. rules, laws and constitutions, as well as informal constraints, e.g. norms of behaviour, conventions and self-imposed codes of conduct.

North (1994) states that: "It is the interaction between institutions and organisations that shapes the institutional evolution of an economy. If institutions are the rules of the game, organisations and their entrepreneurs are the players".

He argues that the emerging organisations are a direct reflection of the opportunities provided by institutions, e.g. if a country's institutional framework rewards innovation, innovative organisations are bound to flourish.

As the interest of this thesis is focused mainly on the framework of analysing innovation from a systems perspective, drawing parallels between the generic definition of a system as defined by Blanchard and Fabrycky (1998) and the structure of a system of innovation is almost automatic. A number of interesting conclusions can be drawn from a study by Carlsson et al (2002), where the same general definition of a system was applied to technological innovation systems.

**Table 2-1: Structure of Systems of Innovation**

| Generic System Definition (Blanchard and Fabrycky, 1998) | System of Innovation (Carlsson, 2002) |
|---|---|
| Component | Organisations |
| Relationship | Linkages between organisations |
| Attributes | Institutional environment |

Although Carlsson formulated this definition for technological systems, it is also generally applicable to systems of innovation in the structural sense. This is therefore a useful starting point in terms of defining the system for the purpose of the model building study.

As North pointed out, the institutional environment shapes the way that organisations are formed but is, in turn, shaped by the way that organisations interact within a system. The following section documents and critically analyses the views of several researchers on the topic of NSI.

## 2.5 Research on the NSI Framework

Since its original formulation, the concept of systems of innovation has attracted the attention of many researchers working in institutional economics and innovation as well as policy-makers in both developed and developing countries (Niosi, 2002). The remarkable diffusion of the concept has led to its application in several countries and areas. Chris Freeman, Bengt-Ake Lundvall and Richard Nelson were the main pioneers of the system of innovation framework. The following sections aim to discuss their work and views shortly.

### 2.5.1 Comparative analysis of innovation systems

Richard Nelson assembled a number of case studies to describe the main features of the innovative systems of high, medium, and low-income countries (Nelson, 1993). Nelson defines the NSI as: "...The set of institutions whose interactions determine the innovative performance of national firms". This study emphasises the influence and role of system specific institutional factors stimulating or impeding innovation or technological change. The study revealed tremendous differences between nations regarding their ability to initiate, import and diffuse new technologies. A collection of these studies has been published in Nelson's book titled "National Innovation Systems: A comparative Analysis". The main findings from this study are as follows (Nelson, 1993):

- *innovation processes cannot strictly be separated between nations*: although this approach is useful for analytical purposes, R&D activities are increasingly carried out on international level. While S&T workers are increasingly mobile across national borders, communication technology enables firms to communicate over huge distances. Goods are also imported and exported between nations

- *it is not always reasonable to make comparisons between countries*: differences between nations in their innovative behaviour and economic patterns were evident. The differences were less obvious between nations with a similar level of development. Nelson states that observed differences could be due to differences in the political circumstances, priorities, size and affluence of countries
- *private firms are not the only contributing factor:* the public and educational sector also plays an important role in influencing nations' innovative ability
- *low R&D statistics not always indicate low innovative performance:* the study revealed that low R&D performance does not always imply low ability to innovate. This outcome confirmed that innovation is not merely a linear process or simply outcome of R&D spending; and
- *strengths cannot be transferred easily:* innovative capabilities and economies develop over time. This makes it extremely difficult to transfer strengths from one innovation system to another. The degree of difficulty increases when the differences in the size, economic structure and institutional arrangements of countries are significant.

### 2.5.2 The NSI and interactive learning

Bengt-Ake Lundvall led a research team at the Aalborg University Centre to investigate the analytical content of the notion of NSI by looking at the roles that users, the public sector and financial institutions play (Lundvall, 1992). Lundvall defined an NSI in terms of 'elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge... either located within or rooted inside the borders of a nation state'. He acknowledges the influence that historical experience, language and culture will have on the national characteristics of the following elements:

- internal organisation of firms
- inter-firm relationships
- the role of the public sector
- institutional set-up of the financial sector; and
- R&D intensity and organisation.

Lundvall published his contribution, titled: "National Systems of Innovation: Towards a Theory of Interactive Learning" (Lundvall, 1992). His study is based on the following two sets of assumptions:

- knowledge is the most important resource in the modern economy. The most important process is therefore learning; and
- learning is predominantly interactive and therefore a socially embedded process. An understanding of the process ultimately involves consideration of the institutional and embedded context.

Lundvall acknowledges and emphasises that innovation cannot be localised exclusively in national borders.

Lundvall's work, "National Systems of Innovation: Towards a Theory of Interactive Learning", also documents the views of several other authors on the role of interactive learning. Johnson (1992) argues that where the economy is viewed from an institutional point of view as a process of communication and cumulative causation, learning can be conceptualised as the source of technical innovation. He adds that nearly all learning processes are interactive, and influenced by their content, rate and direction of the institutional set-up of the economy.

Johnson also discusses how institutions influence learning, growth of knowledge and innovations, which he defines as sets of habits, routines, rules, norms and laws that regulate the relations between people and shape human interaction. Given their ability to reduce uncertainty and thus the amount of knowledge needed by each individual, institutions are fundamental building blocks in society.

Johnson's learning argument can be summarised as depicted in Figure 2-4.

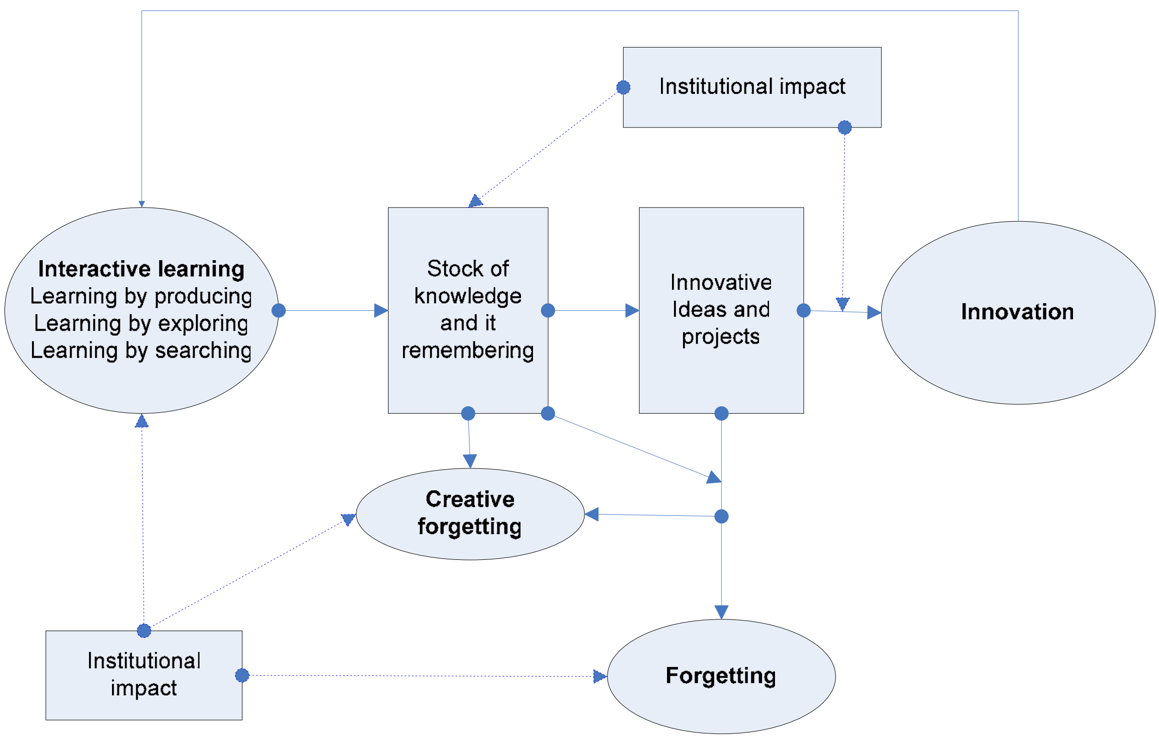



**Figure 2-4: The Relations between Learning, Growth of Knowledge and Innovation**

- Interactive learning in all its forms, i.e. learning-by-production, learning-by-searching or learning-by-exploring, contributes to the stock of economically useful knowledge.
- The stock of knowledge must be guarded against deterioration through continuous re-learning or remembering by doing.
- The stock of knowledge is primarily diminished through different kinds of forgetting. Creative forgetting could cause a feedback loop to increase the

knowledge stock.

- Parts of the new knowledge might translate to innovations through a selection mechanism.
- New knowledge must be applicable in many processes and products. Institutions must have the ability to exploit it.
- Johnson concludes by saying that the flows of knowledge, remembering and forgetting as well as the selection mechanism are shaped by institutional factors.

Andersen (1992: 68) stresses the importance of national linkages. He emphasises the importance of co-operation between firms as a necessary supplement to competition through analysing user-producer interaction. Andersen believes that many innovations/new possibilities are often discovered as by-products of existing production and sales activities. Often, more ambitious searching for and learning about new products also start with existing products and processes. He states that two 'lists' of demand specifications can be visualised, one containing errors, repair problems and larger breakdowns, while the other contains a list of ideas and wishes for new features, facilities and performance measures.

Christensen (1992: 147) discusses the importance of finance in the innovation process. "One of the most important institutional conditions for the process of innovation is the possibility of financing the process".

The role of finance in the HES is not discussed in this paper as the emphasis is mainly on the role of finance in firms. He draws attention to the importance of institutional factors in the financial system that supports innovation. Christensen stresses the influence of a degree of uncertainty surrounding the investment as well as risk adversity on innovation. His discussion also centres on the importance of interactive learning in finance as the lender-borrower close contracts repetitively and in the process, accumulates knowledge.

Freeman (1992:170) contributes to the volume by discussing formal scientific and technical organisations in the NSI. He believes that although R&D is not the only source of technical change, it remains one of the main points of entry for new scientific development and the main focus for the development of new products and processes in most branches of industry. Freeman also focuses on the importance of organisational innovations in the NSI.

Freeman (1992:170) believes that as technology has become more complex, the role of the public sector increases in importance. Gregersen's (1992:128) discussion on the role of the public sector in creating, maintaining and developing the modern NSI argues that the public sector is one of the most important users of innovations. Public authorities define the room for 'innovative manoeuvre' by designing institutions, i.e. standards, patent, acts, etc., and other regulatory activities to control innovation as well as diffusing new products and processes.

This volume pays close attention to the roles played by finance, firms and the public sector. Lundvall (1992: 14) admits however that the volume does not contribute much to the vital role that the educational sector plays in the NSI. The vital point that the volume makes is the learning and the role played by R&D as a form of learning, a view that holds extreme merit for the purpose of this thesis.

### 2.5.3 Technologies, institutions and organisation

Charles Edquist offered an integral contribution with his book, entitled Systems of Innovation: Technologies, Institution and Organisations (Edquist, 1997). The volume aimed to determine the common foundations of the system of innovation approaches (Archibugi et all, 1999). Edquist (1997:15) identified nine common characteristics from the national systems of innovation literature. He focused particularly on the commonalities of the different approaches:

- *innovation and learning processes play a central role:* this contrasts with neo-classical analysis, where technological change is treated as an occurrence outside the economic system. Products and processes can be created, i.e. innovation, through the production of new knowledge or combining existing knowledge
- *holistic and interdisciplinary nature of the NSI approach:* the system of innovation approach, i.e. national, sectoral and technological, strives to include all the determinants considered important in the innovation process. The approach is interdisciplinary in including economic factors, institutions and organisations
- *the natural inclusion of a historical perspective:* history matters in innovation processes, innovation occurs over time. Innovation is also path dependent, i.e. small events are reinforced through positive feedback loops and become crucially important. Organisations also develop over time. The accumulation of knowledge and skills is central
- *differences between systems and a non-optimality:* systems of innovation have different structures of production. In some countries, raw material based production is dominant, while other countries find knowledge-intensive production more important
- *emphasis on interdependence and non-linearity:* innovations can be considered as the establishment of products and processes through the creation of new knowledge elements or combining existing knowledge elements in a new way. Knowledge elements do not originate at a central point but rather with different actors and agents (universities and firms). The literature analysed strongly emphasises the complex interaction of different elements with each other
- *the incorporation of product technologies and organisational innovations:* technological change is closely intertwined with organisational change, which is a key process of innovation. Edquist states that organisational change can in principle be analysed from the systems of innovation approach
- *the central role of institutions in the NSI approach:* in all the definitions presented in the literature, institutions that influence innovations are central elements
- *the system of innovation concept has a conceptually diffuse nature:* none of the major authors provide a clear guide on what to include in a (national) system of innovation. Problems exist around the vagueness of some concepts, such as ‘institutions’; and
- *the focus of the literature on conceptual construct rather than a rooted theoretical*

*framework:* although the system of innovation approach is not a formal theory, it is rooted in various theories of innovation.

In Edquist's volume, Galli and Teubal (1997) contributed to the dynamic view on NSI. Their work included a description on the functions and building blocks of the NSI. They believe that following WWII, the NSI developed within a relatively sectoral or subsystem configuration, which can schematically be based on three R&D performing sectors, i.e. business, public and universities, with relative weak linkages, and a fourth basic infrastructural subsystem, i.e. bureau of standards, patent office, etc.

Galli and Teubal (1997: 346) stress the importance of distinguishing between function and organisation, as they tend to play increasingly more central roles. Galli and Teubal also introduce the concepts of hard and soft functions (Galli and Teubal 1997: 347).

Hard functions require hard organisations, those equipped with laboratories and performing R&D. These functions include:

- R&D involving universities and public and non-profit organisations; and
- supply of scientific and technical services to third parties, i.e. business sector and public administration, by industrial firms, technological centres, technical service companies, universities, governmental laboratories and ad hoc organisations.

Soft functions and related organisations, those without laboratories and not performing R&D, include the following:

- diffusion of information, knowledge and technology towards economic and public operators interfacing between knowledge suppliers and users. Such bridging organisations include various forms of innovation centres and liaison units at universities and public laboratories, etc.
- policy-making by government offices, technology assessment offices, academies universities as well as ad hoc for a national committees and councils, etc.
- design and implementation of institutions concerning patents, laws, standards, certifications, regulations, etc. These functions are usually performed by public or intermediate organisations;
- diffusion/divulgation of science culture through science museums, science centres, etc.; and
- professional co-ordination through academies, professional associations, etc.

Several linkages connect various players or components. Three types of linkages can be identified (Galli and Teubal, 1997: 347):

- market transactions
- unilateral flows of funds, skills, and knowledge, both embodied and disembodied within an NSI as well as externally between organisations and others located in other countries or NSIs; and
- interactions, such as user supplier networks.

Linkages between the players and components can be facilitated, enabled or embedded in a wide arrangement of institutional arrangements, e.g. laws, norms, policy-induced incentives, specific allocation, agreements, etc. Interactions between S&T can be in different contexts, namely geographical, sectoral or technological. Government plays a major enabling role through policy-making and the generation of linkage mechanisms and incentives.

Galli and Teubal identified major trends within the basic building blocks of the national system of innovation.

*Building block 1: universities*

- Universities provide higher education and perform basic research, thereby playing a key role in an NSI absorptive and generative capacity.
- Multi-disciplinary research has increased considerably to address the need for interdisciplinary approaches in complex problem solving.
- Diffusion of generic or mission-oriented research programmes.
- Increased interaction with the business sector to assess the achievements of basic research and to direct the performance of scientific activities.
- Establishment of interface units that offer the business sector a low transaction cost access mechanism to skills and knowledge.
- Establishment of university-industry joint research/technology development centres.

*Building block 2: public sector*

Three major kinds of R&D organisations exist in the public sector:

- mission oriented bodies and agencies supplying required knowledge, both technical and scientific, to ministries and other regional authorities
- basic or general bodies, e.g. CSIR and NRF; and
- publicly owned companies operating in areas such as oil, petrol and minerals etc., for example SASOL. These companies usually play a key role in an NSI, given the relatively high share of R&D performed in their laboratories. These companies also define technical standards for a vast number of supplying firms.

The public sector supplies the business sector with more and more scientific and instrumental capabilities. This is a result of budget cuts forcing the laboratories to look for innovative roles in the NSI. Publicly owned companies were also forced to restructure due to privatisation or budget constraints.

*Building block 3: the business sector*

Innovation processes in firms are increasingly moving away from a linear R&D process model to a model emphasising the full integration of roles among technical and market functions as well as the external provision of information, technology and advisory services. Stronger linkages between manufacturers and their customers are created through knowledge transfers on the better use of products.

Suppliers consequently play a more important role in updating and maintaining the technical standards and production quality of their customers. R&D contractors specialising in a field are an increasingly common occurrence, as is the spread of engineering, consulting and information service companies.

*Building block 4: infrastructural subsystem*
The infrastructural building block might play an increasingly important role in business sector restructuring and in promoting more interconnectedness among various NSI components. The building block comprises the following subcomponents:

- traditional infrastructural components with both the soft and hard functions, including patent offices, bureau of standards, geological surveys, extension services, statistical offices, science museums and science centres
- technological infrastructure; and
- policy development.

## 2.6 National Competitiveness

Porter (1990) contributed to the field by developing a framework to analyse relationships between the characteristics of national or regional systems of innovation and innovativeness in terms of industry competitiveness.

Porter indicates that proximity plays a fundamental role in competitiveness and that knowledge of national characteristics and capabilities is crucial to building competencies. Porter identified four broad attributes of a nation involved in shaping the environment where local firms compete.
forthwith referred to as the ‘diamond’, depicts the four determinants of a nation that can either promote or impede the creation of competitive advantage (Porter, 1990).

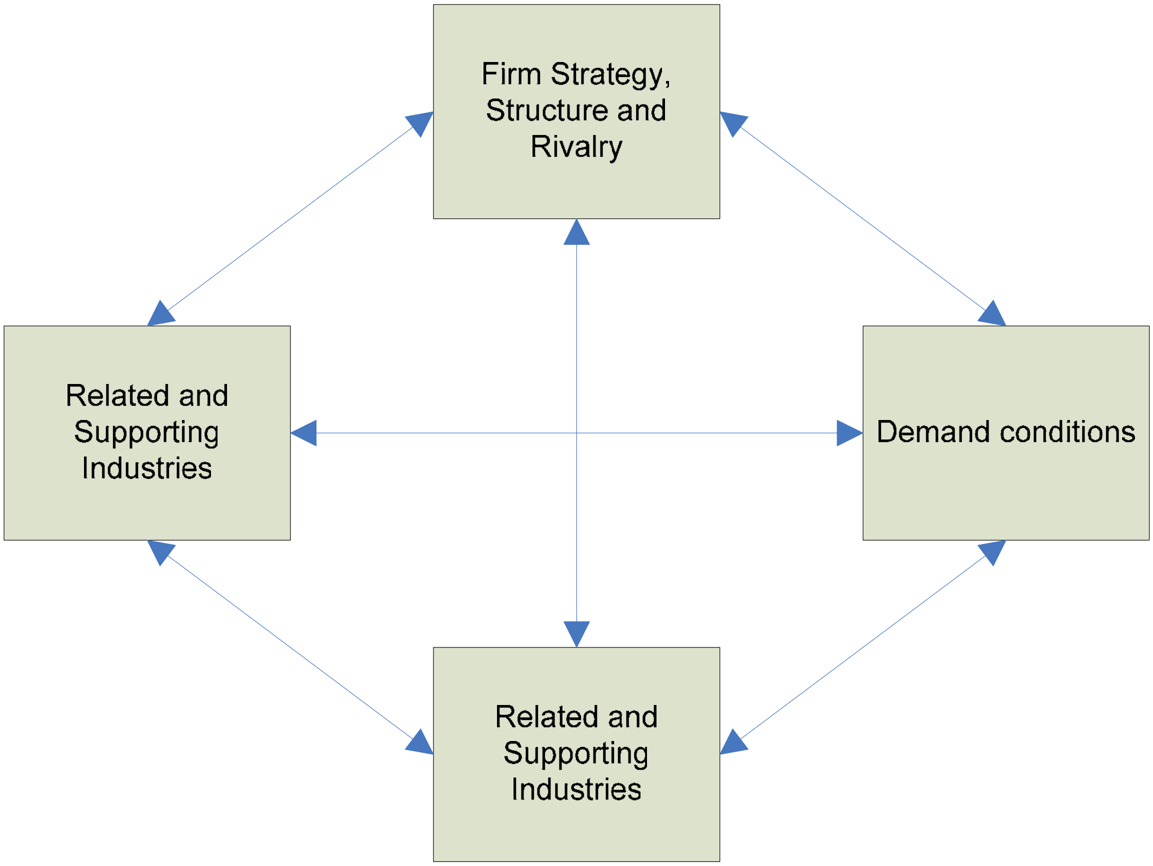



**Figure 2-5: Porter's diamond**

The four sides of the diamond comprise:

- factor conditions, i.e. human resources, physical resources, knowledge resources, capital resources and infrastructure
- demand conditions, especially 'competent demand' as represented by, for example, technically sophisticated customers. The *quality* of demand is more important than the *quantity* of demand
- links to related and supporting industries; and
- the firm's strategy, structure and rivalry refer to the conditions within a country that determines how companies compete as well as how they are created, organised and managed.

Although each economic activity is viewed primarily as an industry, the activity also forms part of a cluster of activities and agents as opposed to occurring in isolation. Porter also stresses that government could influence the creation of a competitive advantage either positively or negatively. Viewing government as an influencer or the national 'diamond' both clarifies and highlights this statement:

- government can influence *factor conditions* through subsidies, policies, educational policies, etc.

- the role government could play in shaping local demand conditions are often more subtle. Government may establish local product standards or regulations that could influence buyer needs. Government itself is often a major buyer of many of the nation's products, i.e. defence goods, telecommunication equipment, aircraft)
- government policy influences firm strategy, structure and rivalry through devices such as capital markets regulations, tax policy and antitrust laws; and
- government could shape and control relating industries by regulating the advertising media, supporting services, etc.

Because of the industry focus, Porter strongly emphasises the role of competition among actors within industries, thus market competition, while suppressing non-market interaction with entities outside the industry. In this sense, the system definition is narrower than in the national innovation system approach. The main focus is on a static or comparative static analysis (Carlsson, 2002).

## 2.7 Summary

To develop a systems model of R&D in the South African NSI, certain conclusions can be drawn regarding the nature and character of a system of innovation. The analysis of the literature on NSI also resulted in a higher level view being developed.

Human resources in the economy are organised in and belong to organisations within an NSI. In line with the belief that no system functions in isolation (Blanchard and Fabrycky (1998:2)), organisations can be described as systems that form part of a bigger system, e.g. the sector they belong to. Before discussing the role of organisations in more detail, the level of the individuals in the organisation is scrutinised. Organisations consist of individuals with certain capabilities. Individuals in these organisations possess, amongst others:

- *attributes:* tacit knowledge, skills or a capability to learn and forget, a role in the organisation (Lundvall, 1992), (Romer, 1990). Individuals also possess an ability to use the physical and capital resources as well as the infrastructure to perform their duties. These individuals are therefore important building blocks of organisations; and
- individuals also have relationships with other individuals (Linkages).

Nelson (1993), North (2001), Edquist (1997), Balzat (2002), Freeman (1992) and Johnson (1992) acknowledge the important role that organisations and institutions play in the development of organisations and their attributes within the NSI. These authors argued that the systemic nature of the NSI could be explained through the organisations in the system.

There are different types of organisations in an economy. Organisations can also be organised into sectors in the NSI. Lundvall (1992), Edquist (1997) as well as Galli and Teubal (1997) acknowledge the importance of the business sector but also emphasises the importance of organisations in the educational and public sectors. The following figure is the author's view on the basic structure of an NSI as described by Galli and Teubal (1997).

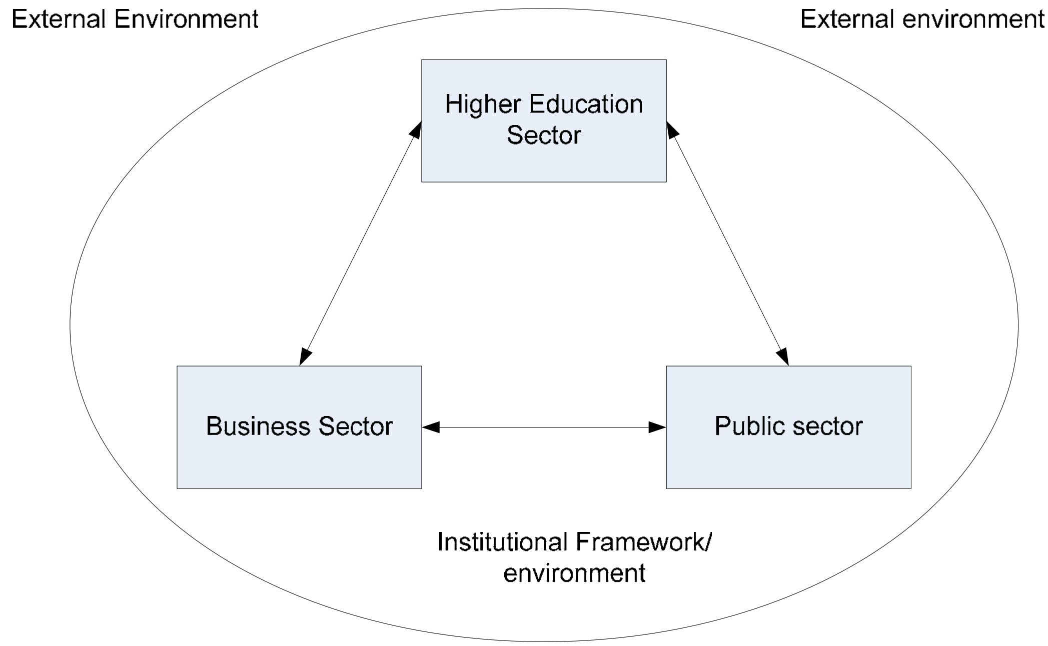



**Figure 2-6: Simplified Structure of the NSI**

Examples of organisations in the three sectors include the following:

- educational sector: This sector comprises higher education organisations, such as universities. The South African HES is characteristically only a recipient of funds for R&D, with which it is required to provide talented human resources, meet local needs in knowledge generation related to scientific progress, create and sustain centres of excellence in the social and physical sciences and engineering as well as participate in consortia and other joint research programmes (DACST, 1996: 22)
- public sector: This sector consists of science councils, publicly owned companies, museums and government departments. The main function of this sector is to define standards, perform research, diffuse knowledge, formulate policy, human resource development, the provision of infrastructure and the allocation of resources (DACST, 1996: 17)
- private sector: This sector includes all the other firms in the economy. The main function of this sector is to create wealth and to innovate; and
- infrastructural sector: This sector includes the components of the system, which enhances interconnectedness between other components in the NSI. Some of the components in this sector include policy making bodies, technology infrastructure, science centres, etc.

Figure 2-6 also depicted the interactions and relationships between players. These interactions and linkages are crucial to the system's nature and performance. Galli and Teubal (1997), Andersen (1992), Edquist (1997) and Lundvall (1992) agree that the linkages within an NSI are a vital contributing factor to the development and innovative behaviour of the system.

The environment within which the NSI interacts is also imperative. The NSI is not an isolated system and is influenced by other subsystems of an economy, for instance the legal system, tax system, financial system or the labour market (Balzat, 2002). Nelson (1993) and Lundvall (1992) also stress the influence of globalisation, the development of telecommunication technologies and the emergence of global companies on innovation processes.

We can conclude that government might well play an integral part in creating an environment conducive to innovation. Porter stresses the role that government plays in ensuring that the environment in which the system exists is inductive to innovation and R&D. The institutional framework contributes to the environment. According to North, the environment will determine the attributes of the organisations in the NSI. Galli and Teubal (1997) as well as Gregersen (1992) agree on the role of the public sector, and in particular government, in ensuring the quality of the linkages in the NSI.

# 3 MODELS OF R&D AND INNOVATION SYSTEMS

## 3.1 Purpose and Outline of the Chapter

The previous chapter introduced the concept of an NSI. The analysis and descriptions of other scholars' work in the previous chapter were mainly descriptive and textual analyses. Up to this point, no attention has therefore been given to the empirical measurement and treatment of innovation or systems of innovation.

This chapter will thus both review a number of the existing empirical analysis studies as well as discuss various authors' theories and frameworks.

The chapter also includes a discussion on the quantitative measurement of S&T as well as the shortcomings experienced with using these indicators. Various important econometric models developed for modelling the knowledge accumulation and knowledge based growth are also scrutinised. A section is allocated to analysing a number of measurement instruments aimed at gauging an NSI's efficiency and effectiveness.

The second half of the chapter focuses on existing system dynamics models of the R&D function and R&D systems. The chapter is concluded with the identification of a knowledge gap in terms of modelling systems from an NSI point of view as well as the development of a model for R&D activities in the South African system of innovation.

## 3.2 Quantitative Measurement of Science and Technology

The term 'indicator' is used with its traditional methodological connotation, namely operationalised attribute, ideally a quantitative form, of an abstract concept. Interest in the development of indicators stems from the need to monitor and enhance S&T capabilities.

S&T indicators can be defined as a series of data designed to answer questions surrounding the existing state of and/or changes in the science and technology enterprise, its internal structure, its relationships with the outside world and the degree to which it meets the goals set internally or externally (Fabian, 1979). The aim of S&T indicators is similar to that of social indicators, i.e. to obtain a picture of the state of S&T and to anticipate the consequences of scientific advances and technological change (Sirilli, 1998).

As noted previously, the study centres mainly on the R&D function within the NSI. This section will thus focus primarily on those indicators linked directly to R&D. The tendency in R&D assessment has been to emphasise quantitative input indicators, while the difficulty of assessing R&D output has tended to accentuate indicators such as expenditure on R&D, number of R&D personnel and number of R&D projects in a particular area. R&D output indicators as embodied in publications, patents and trade secrets, are commonly used in the industrialised countries. Output indicators tend to facilitate research intensity indicators, including publications per capita and per institution, discipline and country. R&D indicators can be categorised as follows (UN, 1997):

- *input:* focussing on resources, mainly human and financial, but also on information resources. Examples include R&D inputs collected in the OECD economies according to the procedures and categories described in the Frascati manual
- *output:* including new or reformulated knowledge as in embodied products, processes,

patents and publications:
  - patent data, i.e. records of the United States Patent Office (USPTO) and the European patent office and
  - bibliometric data on patterns of scientific publication and citation.
- *quantitative:* addressing input resources, i.e. the number of researchers, funding support as well as output, including publications, patents as well as financial indicators such as Return-on-Investment (ROI) and break-even index; and
- *qualitative:* focussing on input and output quality, originality, utility, conformity with original plans, sound use of resources, the quality of linkages to production and services sector as well as R&D communities within the country, the region and abroad.

This section documents various formalised measurement manuals for data on innovation and R&D. For a number of years, the Frascati manual was the only such manual, with four other manuals added recently. The Frascati manual family is based on experience gained from collecting R&D statistics in OECD member countries. The manual is a result of the collective work of national experts in the working party of National Experts on Science and Technology Indicators (NESTI). Over the past 40 years, the group, supported by an effective secretariat, has elaborated on the concept of S&T indicators and consequently developed a series of methodological manuals known as the Frascati Family, which includes manuals on the topics tabled below (OECD, 2002b):

**Table 3-1: The Frascati Manual family**

| The Frascati Family | |
|---|---|
| R&D | The Measurement of Scientific and Technological Activities Series<br><br>Frascati Manual: Proposed Standard Practice for Surveys of Research and Experimental Development<br><br>R&D Statistics and Output Measurement in the Higher Education Sector. 'Frascati Manual Supplement' (OECD, 1989b) |
| Technology balance of payment[1] | "Manual for the Measurement and Interpretation of Technology Balance of Payments Data – TBP Manual" (OECD, 1990) |
| Innovation | OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data – Oslo Manual (OECD, 1997a) |
| Patents[2] | "Using Patent Data as Science and Technology Indicators – Patent Manual 1994" (OECD, OCDE/GD(94)114, 1994b) |
| S&T personnel | "The Measurement of Human Resources Devoted to Science and Technology – Canberra Manual" (OECD, 1995) |

The following sections analyse the formalised measurements of R&D input and output in more detail.

### 3.2.1 The measurement of R&D input

The Frascati manual is devoted to measuring R&D inputs. R&D, in turn, covers both formal R&D in R&D units and informal or occasional R&D in other units. The Frascati manual (OECD, 2002b) both presents the key guidelines and methodology for collecting R&D data and provides classifications to be used when collecting statistics. The manual also contains

[1] Deals mainly with problems of classifying and interpreting existing information.

[2] Deals mainly with problems of classifying and interpreting existing information.

definitions of the basic concepts associated with R&D and discusses how R&D relates to other relevant scientific and technological activities impacting on innovation and consequently also on socio-economic development.

South Africa has been conducting Frascati-style R&D surveys since shortly after the first manual was published in 1963. The first R&D survey based on OECD guidelines was conducted in 1966. Over the next 25 years up to 1993/4, South Africa conducted 18 regular official surveys. See Appendix A for a detailed account of the surveys conducted in South Africa.

### 3.2.2 Innovation surveys

The OECD was responsible for developing a framework for the measurement of innovation output. The Oslo manual on innovation surveys uses the systems of innovation approach from a theoretical and conceptual point of view. This approach defines innovation as a device aimed at solving problems arising at different stages. The manual covers innovation in the business enterprise sector and includes the following topics:

- innovation at the firm's level
- it concentrates on Technological Product and Process (TPP) innovation, with optional guidelines for other forms, such as organisational change; and
- it covers diffusion up to 'new to the firm'.

Following the first round of surveys performed in the OECD countries, various developing countries, such as Venezuela, Argentina and Brazil, joined in the phenomenon by conducting surveys based on the Oslo manual. These survey results indicated a number of definite differences between the Latin American firms and its First World counterparts. The differences were specifically obvious in terms of the nature and intensity of the firms' efforts geared towards technological innovation (Salazar, 2004), (Bogota, 2001):

- a much smaller percentage of firm effort is geared towards R&D, while innovation has increased in importance
- less effort is invested into basic than applied research
- innovation is based primarily on the acquisition of technology embodied in capital equipment
- the importance of organisational change in innovation processes; and
- fragmented flows of information within national systems of innovation.

Discussions were initiated to ultimately adapt the Oslo manual towards the specific needs of developing countries. These discussions resulted in the Bogota manual (2001), a manual based on the methodological conceptual and methodological base provided by the Frascati and Oslo manuals, but with alterations according to the unique character and specific characteristics of innovation systems and firms in the Latin American countries.

The Bogota manual has been revised once and has been used in Argentina, Uruguay and Colombia.

In South Africa, only one Oslo-type innovation survey has to date been carried out by the University of Pretoria in co-operation with the Eindhoven University of Technology in the Netherlands (Oerlemans L. A. G. et al, 2003).

One criticism of the innovation surveys approach is that its main concern is measuring inputs and outputs to innovation rather than focussing on the measurement of the processes, dynamics, relationships and interactions that affect innovation. Although the Oslo manual on innovation surveys uses the systems of innovation approach from a theoretical and conceptual point of view (Salazar, 2004), the questionnaires based on the manual collect little information on the dynamics of national and regional innovation systems.

Another option in measuring R&D and innovation output is to employ existing data sources. A substantial amount of methodological work was required before recommending an international standard practice for using existing sources to derive S&T indicators. Manuals dealing with both the technology balance of payments as well as the use of patents as S&T indicators have been published (OECD 1990, 1994b).

The following sections discuss the use of bibliometric data and patent data in the measurement of R&D output.

### 3.2.3 Bibliometric data

Since the 17$^{th}$ century, scientists have communicated their findings in international publications. This form of communication or the exchange of research results has become a crucial aspect of scientific endeavour.

The principle units of measuring in bibliometrics are scientific publications (Verbeek et al, 2002). A scientific publication usually contains a title, the names of the authors and their institutional affiliation. Although far from perfect, the publication is adopted as a building block of science and a source of data.

This approach defines the basic assumptions of bibliometrics. Bibliometric assessment of research performance is based on the principle that where a scientist have something important to say, he/she will publish the findings in the open international journal literature (Van Raan, 2004: 25). There are however some limitations to this approach. Scientific publications provide only a limited view of a complex reality as:

- journals are not the main carriers of scientific knowledge in all fields; and
- journal articles are not equivalent and differ widely in importance.

In most cases, the daily practice of inspired scientists indicates that they tend to communicate their results in scientific publications.

Work of some importance invokes reaction from colleagues. When scientific publications are published, we often see authors referring to their own earlier work or the work of other scientists. Scientific publications also reveal a number of citations to other publications that the author believes relevant to his/her article in some way (Verbeek et al, 2002). This process of citation is complex. As with publication counts, citations are also not an ideal monitor for performance. Citation analysis is based on scientists' reference practices, which means that the motives for referencing and citation might vary considerably. Van Raan (2004) concludes however that although the motives for referencing might differ considerably, the degree of uncertainty is not high enough to result in the practice of using citations in analysis loosing all meaning.

*The use of Bibliometric data in the describing the 'forgetting phenomenon'*

Scientists use other people's work in a distinctly characteristic manner. Various studies have been conducted using bibliometric data to estimate and study obsolescence of knowledge (Pollman, 2000). In these studies, two basic approaches have been distinguished, namely, the diachronous and the synchronous model:

- the diachronous approach is concerned with the use of a given set of publications in successive years; and
- synchronous studies proceed from the present to the past (Glanzel 2004).

When discussing the lifetime use of scientific information within the framework of documented science communication, it refers to the relevant information performing its intended function, namely, to be read and to impact on scientific research. The lifetime use of scientific information is therefore in part measurable by citations. A lifetime can consequently be interpreted as the period after scientific publications are no longer cited (Glanzel, 2004). In Bibliometric research the general conviction exists that the decline of references to a specific article per annum is exponential.

The following section discusses the use of patents as a measure of R&D output.

### 3.2.4 Patent data

Since its inception, the study of technological change has been hampered by the scarcity of appropriate data and, in particular, by the lack of extensive coverage for good innovation indicators (Jaffe and Trajtenberg, 2002: 25). Patents seem to be one important exception, since they are the only manifestation of inventive activity covering virtually every field of innovation in the majority of developed countries and over long periods of time. Jaffe and Trajtenberg (2002) state that patents have long since been reputed as a rich and potentially fruitful source of data for the study of innovation and technical change. The current stock of patents exceeds 6 million, with an additional flow of more than 150 000 patents yearly (as of 1999 to 2000).

A patent acts as a temporary monopoly to inventors for the use of a newly invented device. For the patent to be granted at the USPTO, the patent must be (Jaffe, Trajtenberg and Henderson, 2002:53):

- non-trivial, i.e. must appear non-obvious by a practitioner of the relevant technology; and
- useful, i.e. must have potential commercial value.

Smith (1998) explains that the motives driving parties to enter into a contractual arrangement necessarily influence how patent data can be applied as an indicator of inventive activity. As a contract, the patent-system caters to the assignee(s)' basic desire to appropriate profits accruing to the invention while catering to the system's basic desire of having the invention details spread to others, thus allowing the system to build on new knowledge. In line with this view, the state's motives involve:

- creating an incentive for actors in the economy to undertake inventive activities; and
- disseminating detailed information regarding inventive activities for future generations to build upon them.

The pitfalls associated with equating the patenting process with the level of innovative activity are widely recognised (Schmookler, 1966; Pavitt, 1982, 1988; Griliches, 1984, 1990; Trajtenberg, 1990). Griliches (1990: 1669) points out that:

- not all inventions are patentable
- not all inventions are patented; and
- inventions that are patented differ greatly in 'quality' in the magnitude of inventive output associated with them.

The non-rival nature of knowledge as a productive asset creates the possibility of 'knowledge spillovers', whereby one party's investment in knowledge creation produces external benefits by facilitating innovation by other parties (Jaffe and Trajtenberg, 2002: 379). Since Griliches' seminal paper on measuring the contributions of R&D to economic growth (1979), economists have attempted to measure and quantify the extent of knowledge spillovers.

*Patent citations as a measure of knowledge spillovers*
One line of research uses patent citations to identify a paper trail that might be associated with knowledge flows between organisations. Unlike bibliographic citations, patents perform a vital legal function, as it delimits the patent grant by identifying prior art not covered by a grant. Since the citations made from one patent to another has a legal goal and could have certain financial implications, gratuitous citations do not seem to be a concern in the case of patent citations. These citations does however open up the possibility of tracing multiple linkages between inventions, inventors, scientists and firms (Jaffe, Trajtenberg and Henderson, 2002: 155).

Jaffe, Trajtenberg and Henderson (2002: 161) classify the links between two patents into three groups:

- firstly, *spillovers accompanied with citations*: this is the case in which the use of patent citations to indicate a knowledge spillover is successfully implemented
- secondly, *citations where there was no spillover*: a more serious issue with the use of patent citation data to indicate knowledge spillovers is the case where the citation was added by the examiner but where the patentee was unaware of the patent being cited. In such a case, it is clear that no spillover occurred; and
- thirdly, *spillovers without generating citations*: an enormous amount of spillovers exist with no citations, since only a small amount of research output is ever patented. Many results of basic research are never patented. Jaffe states that it is plausible that basic research creates the biggest spillover.

Fro this discussion it is clear that the measurement of knowledge spillovers cannot be measured accurately using patent citations. The development and selection of indicators as a measurement of a country's R&D system depends on the goals set by the governing body.

### 3.2.5 Summary

Frascati surveys are used to measure R&D input. These surveys have been conducted in South Africa since the 1960s, thus indicating that time series data of R&D expenditure in the South African R&D system exists.

Only one Oslo-type innovation survey has to date been performed in South Africa. We can therefore conclude that no innovation time series data is available from this source.

The above discussions concluded that patents and scientific publications open up the possibility to perform detailed analysis in the relational structures of technological and scientific activity.

For the purpose of this study, we can conclude that patent data and scientific publications are an imperfect representation of the level of R&D output produced in a system. It is therefore important to acknowledge the shortcomings that may be encountered when following this approach. As these indicators are however the best available at present, the author chooses to go ahead in using these indicators.

## 3.3 Models of Knowledge Accumulation and Knowledge-based Growth

Economists and economic historians have studied the role of technology and technological change from as early as the 1950s (Griliches, 2000). Major economists from Smith, Ricardo, Marshall, Schumpeter and Kutznets were well aware of the importance of the role of technology and technological change and discussed the role it plays in economic growth and tensions in the economy.

At first, students of the subject preferred real and tangible measures of technological change, i.e. diffusion of big inventions of the time, such as tractors or combinations of the spread of hybrid seed and the transistor. This approach however tended to ignore aggregate productivity. It soon proved necessary to incorporate this aspect, as computations of economies seemed to have an extra portion of measured output growth that could not be explained by growth in measured inputs to changes in productivity. Economists realised that a new force at work was responsible for the unaccounted behaviour. Attention consequently shifted to inventive activity as well as formal and informal R&D efforts (Griliches, 2000).

Numerous authors have attempted regression analysis of productivity being related to some form of R&D. Since the first attempts in the late 1950s and early 1960s, the field has grown enormously. Griliches (1992 and 1995) provides a literature review. Many surveys have been done on the literature, listing countless studies around linking R&D and productivity ((Nadiri, 1993), (Mairesse and Mohen, 1995)).

The early studies failed however to provide a means of linking technological change to any overall aggregate result. Griliches (2000:46) states that “it was then relatively easy to think that the right thing to do was to regress the computed productivity numbers on some measure of R&D or inventive activity in the search for an explanation for it, treating R&D and scientific activity as another form of investment that creates a kind of long lived knowledge capital.”

The following sections describe a number growth models that views knowledge as a capital good.

### 3.3.1 The ideas-driven growth model

Romer’s theory is based on three premises (Romer, 1990: s72):

- technological change lies at the heart of economic growth and provides the incentive for continued capital accumulation. Together, capital accumulation and technological change account for much of the increase in output per hour worked

- technological change also increases due to intentional actions taken by people who respond to market incentives. The model is therefore one of endogenous rather than exogenous technological change; and
- the most fundamental premise is that instructions for working with raw materials are inherently different from other economic goods. Once the cost of creating a new set of instructions has been incurred, this new set can be used over and over at no additional cost.

The third premise implies that technology is a non-rival input, while the second premise implies that technological change takes place because of the actions of self-interested individuals. This thus holds that improvement in technology must confer benefits that are at least partially excludable. The first premise implies that growth is driven fundamentally by the accumulation of a partially excludable, non-rival input.

Non-rivalry has two important implications for the theory of growth:

- non-rival goods can be accumulated without bound on a per capita basis, whereas a piece of human capital, such as the ability to add, cannot. Each person only has a finite number of years to be spent on acquiring skills. When the person dies, the ability to create is lost. The non-rival goods, such as the knowledge created by that person, still remains in the system; and
- treating knowledge as a non-rival good makes it possible to sensibly discuss knowledge spillovers, in other words, incomplete excludability.

The Romer (1990) growth model comprises four inputs, namely capital, labour, human capital and an index of the technology level. While capital is measured in units of consumption goods, human capital is the distinct measure of the cumulative effect of activities, such as formal education and on-the-job training, ultimately measured by counts of people.

This theory articulates the economic foundations for a sustainable rate of technological progress. Romer's model (1990) employs the national ideas production function, i.e.:

$$\dot{A} = \delta H_A A_j \qquad \textbf{3-1}$$

This function holds that the aggregate stock of designs ($\dot{A}$) is a function of the total human capital employed in research ($H_A$). The stock of knowledge available to these researchers ($A$). $\delta$ is the productivity parameter. Romer's model is endogenous in two ways.

The R&D productivity and economic return from R&D ultimately determine the share of the economy devoted to the R&D labour market. In other words, where R&D activities generate money, money is allocated to the sector. A larger portion of the economy devoted to the R&D sector will result in more people being employed in the ideas generating sector. From this, it can be concluded that devoting more people to research leads to a higher rate of production of new ideas.

Productivity of new ideas is sensitive to the stock of ideas available. This ultimately results in a snow-ball effect: where there is current know-how or where ideas have been developed before, it is much easier to develop even more ideas. From this, it can be concluded that the larger the stock of knowledge and ideas in a country, the higher the productivity of idea workers in the economy.

This section briefly discussed Romer's endogenous growth model. In general, the literature scrutinised agrees that these factors included in Romers' model are crucial in explaining economy-wide innovation (Carlsson, 2002). Although Romer's model includes the crucial factors fundamental to R&D-based growth, it does not account for the diminishing returns to scale phenomena. The following section describes Jones' model of semi-endogenous growth.

### 3.3.2 Semi-endogenous growth theory

Jones (1995) believes that Romer's R&D-based model of economic growth is responsible for a prediction of a scale effect. If the R&D resources in the system are doubled, the per capita growth should also double automatically. Empirically, this prediction receives little support.

Jones suggests a refinement of the term 'endogenous' growth and argues that growth is endogenous in the sense that technological progress, which generates long run growth, results from R&D undertaken by profit maximising agents. He continues that long run growth is not endogenous as stated in the Romer model because traditional policy changes have long run growth effects. Jones thus proposes a 'semi-endogenous' growth model.

Apart from the specification of the R&D equation, the growth model proposed by Jones (1995) is very similar to Romer's growth model (Romer, 1990).

The R&D-based models in the endogenous growth literature (Romer (1990), Grossman and Helpman (1991a, 1991b, 1991c), Aghion and Howitt (1992)), share the counterfactual prediction of 'scale-effects'. This implies that an increase in the level of resources devoted to R&D should automatically increase the economy growth rate.

The prediction that the economy growth rate is proportional to the size of its labour force is however easily falsified. The scientists involved in R&D activities in the USA has increased from 160 000 in 1950 to nearly a million in 1988, yet the growth rate in America has not demonstrated anything close to a five-fold increase. Similar patterns can be seen for countries such as Japan, Germany and France where growth rates were constant and in some cases even declining. These observations led to Jones's claim that the assumption embedded in the R&D equation that the economy growth rate is proportional to the level of resources devoted to R&D is obviously false.

Jones proposes his model of semi-endogenous growth and follows the reasoning of Romer/ Grossman-Helman/ Aghion-Hewitt by stating that the Knowledge Stock ($A$) is the accumulation of ideas, and people develop ideas. The change in knowledge will consequently be equal to the number of people attempting to discover new ideas ($L_A$) multiplied by the rate at which R&D generates new ideas ($\bar{\delta}$):

$$\dot{A} = \bar{\delta} L_A \qquad \textbf{3-2}$$

Furthermore the rate at which new ideas are discovered can also be seen as a function of the amount of knowledge in the economy. Positive spillovers in the production of knowledge, $\delta$

would therefore also increase the level of $A$. When parametrising the arrival rate $\delta$, we get:

$$\bar{\delta} = \delta A^{\phi} \qquad \textbf{3-3}$$

In this equation, $\phi < 0$ corresponds to the case referred to in the literature as "fishing out", in which the rate of knowledge production decreases with the level of knowledge; $\phi > 0$ corresponds to the positive external returns case. Here $\phi = 0$ represents constant returns to scale.

Finally the possibility is considered that the duplication and overlapping of research reduce the total number of innovations produced by $L_A$ units of labour. Arriving at the proposition that $L_A^{\lambda}, 0 < \lambda \leq 1$ belongs in the R&D equation. By incorporating all the above mentioned in the R&D equation Jones arrives at the following:

$$\dot{A} = \delta L_A A^{\phi} l_A^{\lambda-1} \qquad \textbf{3-4}$$

where $l_A = L_A$ in equilibrium. $l_A$ captures the externalities occurring because of duplication in the R&D process.

It can therefore be concluded that Jones' model is consistent with time series models applied in OECD countries. These growth models describe the development of entities dependent on the discovery of new ideas for their growth. It therefore proves sensible to apply these models to countries with advanced economies instead of countries where development can occur due to technology being transferred from other countries.

### 3.3.3 An econometric model of growth for South Africa

Du Toit et al (2004) analyse the determinants of technological progress, i.e. the total factor productivity, by incorporating the principles of endogenous growth theory. Against the background of structural changes in the production structure of the South African economy towards the increased contribution of technology in generating long-run economic growth, specific emphasis is placed on the role of technological progress in modelling the production function. In the past, South African production models primarily assumed constant technological progress over time, i.e. efficiency parameters were estimated as constants. However, production models must allow technology to improve over time to explain growth in output in the presence of diminishing returns to scale production structures.

Du Toit et al's model incorporates the new growth theory by specifying and modelling technology in terms of:

- the number of scientists and engineers in the economy
- the number of patents registered
- certain international factors, such as the degree of openness of the economy and an 'international position' index, constructed as a weighted average of factors such as the exchange rate, foreign investment and the levels of domestic and international competitiveness; and
- the expenditure on R&D is also incorporated in representing the allocation of resources

in the economy towards technology advancement.

Technological progress was subsequently estimated in terms of the standard variables suggested in the growth theory. The two-equation technology-growth model, consisting of a Cobb-Douglas production function and an endogenously specified technology function, is represented by:

$$Q_t = A_t K_t^{\alpha} L_t^{B} \qquad \textbf{3-5}$$

where $Q_t$ is the Real GDP in period t, $K_t$ is Real Capital stock in period t, $L_t$ is total employment in period t and $A_t$ represents technological progress. $A_t$ takes the form of the following equation:

$$A_t = f(NSEDEB, PATENTS, INTPOD \;|R\&D, OPEN) \qquad \textbf{3-6}$$

where $NSEDEG$ is the Number of Natural Sciences and Engineering degrees, $PATENTS$ Number of patents registered, $INTPOS$ = International position index, $R\&D$ = A measure of expenditure on R&D, $OPEN$ = Openness of the economy to international trade

Du Toit and Koekemoer formed a number of conclusions and policy implications from their analysis of the estimation results and the response characteristics of their growth model. An important feature that surfaced from the estimations is that the South African economy exhibits decreasing returns to scale properties in production with regards to capital and labour inputs. The challenges faced by policy makers in South Africa are therefore demanding and multifaceted. These challenges include:

- resolving the structural problems that hamper saving/investment and the labour market absorption capacity of the economy, thereby addressing the decreasing returns to scale property of production with regards to capital and labour
- stimulating technological progress through incentive schemes, e.g. by sponsoring R&D and by creating legal mechanisms to protect the intellectual property rights of those who have invested in generating innovations at great cost
- improving and increasing human capital through training and skills development, thereby narrowing the existing skills gap in the economy. Another challenge is creating an environment where skilled individuals would be willing to participate in the domestic economy. It is therefore vital that the 'brain drain' tend, which at present depletes the stock of human capital of the South African economy, be eliminated
- improving access to existing knowledge, thereby improving the productivity of researchers and inventors
- reducing the barriers for the development and transfer of ideas and knowledge; and
- creating a social infrastructure and policy framework conducive to entrepreneurship and production. History has proven that economies in which the government provides an environment that encourages production and invention are extremely dynamic and successful.

### 3.3.4 Summary

This section discussed both the principal theories that influenced the current theory and views on the process of innovation as well as the part that these theories play in the economic growth of a country. This section documented a critical analysis of the models discussed thus far.

The analysis indicated that Romer acknowledges and identifies various crucial elements contributing to a nation's economic growth, namely R&D workers, a knowledge stock and the productivity with which these R&D workers are employed. Although most scholars agree that these parameters are crucial to economic growth, Romer can however be criticised for being too constricted. We can therefore conclude that Romer introduced a somewhat limited set of parameters.

Jones suggests a refinement of the term 'endogenous' growth and argues that growth is endogenous in the sense that technological progress, which generates long run growth, results from R&D undertaken by profit maximising agents. He disagrees with Romer by saying that long run growth is not endogenous due to traditional policy changes' long run growth effects. Jones thus proposes a 'semi-endogenous' growth model.

Jones' model is consistent with time series models applied in OECD countries. These growth models describe the development of entities dependent on the discovery of new ideas for their growth.

Du Toit et al (2004) analysed the determinants of technological progress, i.e. total factor productivity, by incorporating Jones's developments in growth theory on the South African economy. The outcomes of the model indicate that the South African economy can achieve higher levels of growth through the stimulation of both technological progress and R&D as well as the development of human resources in S&T.

Finally, this section concludes that R&D and the development of a capacity to create new knowledge as well as the ability to absorb new knowledge are crucial for a country's economic development. South Africa is no exception.

Many authors have challenged the character of knowledge as a capital good. The following section discusses the concept of knowledge, measurement methods and concepts around this topic

### 3.4 Knowledge in the Economy

Numerous authors agree on the importance of knowledge and the central role that it plays in the economy. Knowledge is indeed at the heart of organisational forms, as it determines the production, use and transfer of knowledge to such an organisation. Knowledge creates the possibility that a task will be fulfilled, either in the present or the future, by means of a situation-dependant selection, interpretation and valuation of information. Knowledge in terms of in an organisational form is often referred to as the knowledge stored in routines, comprising knowledge of individuals, combined through co-ordination with data and information embedded in machines, computers and other constructs.

Guilhon (2001) refers to the work of Jorna and others when he explains the differences between tacit, coded and theoretical knowledge:

- *tacit or sensory or behavioural knowledge* is knowledge of situations, events and individuals in the form of behaviour, procedures and habits. Tacit knowledge can be obtained by imitation of behaviour, which implies close and detailed observation

- *coded knowledge*, i.e. knowledge in the form of codes, such as languages, icons and formulas, can be taught and trained and is therefore by its nature more easily transferred than tacit knowledge. A prerequisite is however that the code system must be known; and
- *theoretical knowledge*, the reality is not connected to individuals or time, but consists of necessary causal relationships. This form of knowledge is in terms of explanations, for example a 'because' answer in response to a 'why' question. Complex and long 'why-because' chains may appear in this type of knowledge.

Tacit knowledge plays a fundamental role in the development of new knowledge. Nelson and Winter (1982) argues that the ability to deploy R&D activities depends on the involvement of tacit knowledge. Sharing tacit knowledge requires intensive interaction and, in many cases, the physical presence of actors involved in the sharing process (Jacobs, 1999), seeing that articulation of this kind of knowledge in, for example, coded knowledge is difficult or even impossible.

Smith's (1995) definition of knowledge resources offers insight into the nature of knowledge acquisition and the subsequent build-up of the internal knowledge base as a costly and painstaking process in which internal as well as external sources of information are used:

- *knowledge resources are differentiated and multi-layered:* a specific set of resources consists of different forms and levels of knowledge, for instance coded scientific knowledge or tacit knowledge embodied in the experience and skills of employees or other actors
- *knowledge resources are specific:* the knowledge of the firm is restricted and related to the competitive position of the company. This implies restrictions on the competence of the organisation, i.e. path dependency, and delimits the firm's action space. Furthermore, to bypass these restrictions and stretch the firm's competence, knowledge has to be acquired from the firm's environment
- *the development of knowledge resources is costly and cumulative (i.e. path dependency):* the upgrading of resources implies a costly search in which companies, by means of learning and adaptation, gain experience with specific knowledge, thus a cumulative process
- *knowledge resources are internally systemic:* learning is more than the enhancement of technological knowledge. To ensure that the knowledge is translated into innovations, market, finance and human resource knowledge is needed; and
- *knowledge resources are interactive and externally systemic:* interaction with other economic actors is necessary for the acquisition and exchange of knowledge.

Absorptive capacity refers to the firm's repertoire of innovation-directed problem solving routines consisting of knowledge of task execution. Knowledge for innovation is often 'borrowed' from the environment instead of being created by companies themselves (Schmookler, 1966, Von Hippel 1988). To this aim, knowledge for innovation must be absorbed through interaction and co-operation through feedback loops with the network of the firm's business relationships.

In the light of the focus in this thesis, i.e. modelling of the South African R&D system and the central role knowledge plays in the development of new technology; the following sections discuss models that have been developed for the creation and assimilation of knowledge.

### 3.4.1 Modelling absorptive capacity

Cohen and Levinthal (1989) published a seminal paper arguing the dual role that R&D plays in an economy. They argued that R&D not only generates new information, but also enhances the ability to assimilate and exploit existing information. The ease and character of learning in an industry influences both the R&D spending and condition the appropriability[3] and technology opportunity conditions in an industry.

In suggesting that knowledge is a capital good, Arrow (1962) and Nelson (1959) made the assumption that it could be realised without any cost by all firms located within the emission. Although they do not deny the existence of cost of learning, they argued that these costs are relatively small when compared to the costs of creating knowledge. Cohen and Levinthal argued however that the relatively small cost of learning could be ascribed to previous investments to increase absorptive capacity.

Cohen and Levinthal suggested that the long-term cost of learning was substantial and that this cost is borne from the development of a stock of knowledge, which constitutes a firm's absorptive capacity. A significant benefit of R&D is thus its contribution to a firm's knowledge base.

Cohen and Levinthals' model acknowledges the sources of knowledge used by a firm as:

- the firm's own R&D knowledge
- knowledge originating from competitor spillovers; and
- knowledge originating from outside the industry

Cohen and Levinthal assume that an increase in a firm's stock of knowledge will result in an increase in the firm's income. They characterise the determination of an increase in the stock of knowledge (x) as follows:

$$z_i = M_i + \lambda_i(\theta \sum_{j \neq i} M_j + T) \quad \textbf{3-7}$$

$M_i$ represents a firm's investment in R&D, while $\lambda_i$ is the fraction of knowledge in the public domain that the firm is able to assimilate and exploit, and thus represents the firm's absorptive capacity. $\theta$ is the degree of intra-industry spillovers, while $T$ depicts the level of extra-industry knowledge. Other firm's investment in research and development represented by $M_j$ also contribute to $z_i$.

This model holds that a firm's capacity to absorb externally generated knowledge depends on its R&D effort. The equation implies that the firm is unable to assimilate what has not been spilled out. Firms are inherently unable to passively assimilate external available knowledge and therefore have to invest in its own R&D to its absorptive ability. It can therefore be concluded that not only the absorptive capacity but also the appropriateness is endogenous.

[3] Appropriability in an economical sense can be defined as the environmental factors that govern an innovator's ability to capture profits generated by an innovation

Cohen et al. consider the absorptive capacity to be a function of $M_i$ as well as $\beta$. The variable $\beta$ reflects the characteristics of both the outside knowledge, which renders R&D more or less critical to the maintenance, as well as development of absorptive capacity.

Cohen and Levinthal continue to develop a description of the marginal return to the firm's own R&D. For $n$ firms where each firm chooses its R&D levels to maximise profit and they know the R&D levels of the other firms as given (e.g. symmetric Nash equilibrium). This results in each firm's profit to be a function of not only its own knowledge $z_i$ but also the technological knowledge of all the firms in the industry. Rivalry is incorporated by assuming that an increase in a firm $i$'s rival's knowledge will decrease the firm $i$'s profits and marginal benefit from increasing its knowledge. Differentiating $\prod^i$ with respect to $M_i$ yields:

$$R \equiv \prod_{zi}^{i}\left[1+\gamma_{M_i}(\theta\sum_{j\neq i}M_j+T)\right]+\theta\sum_{j\neq i}\gamma_j\prod_{zj}^{i} \qquad \textbf{3-8}$$

Where $R$ yields the marginal returns to own R&D. If this expression is derived for each firm and set equal to 1, i.e. the per unit cost of R&D, a set of equations is generated that characterises each firm's optimal R&D policy given its competitor's R&D levels. When solved simultaneously the equations yield the equilibrium value of each firm's R&D.

### 3.4.2 Modelling knowledge accumulation

In the light of Jones' criticism of endogenous growth theory, Caballero and Jaffe (1993) developed a model for the estimation of the growth of knowledge. The current state of knowledge x (the current level of diffused and not yet obsolete knowledge in the system) is increased in the presence of research labour x. Caballero and Jaffe developed the following equation for the growth of general knowledge:

$$\dot{A} = \Gamma \cdot \lambda n_t \qquad \textbf{3-9}$$

$\Gamma$ is taken to be the contribution of the weighted sum of contributions made by all existing vintages to current innovations. Therefore $\Gamma$ does not include knowledge that is so new that it has not had time to diffuse to innovation workers, nor does it include obsolete knowledge. The knowledge variable is taken to be equal to:

$$\Gamma = \int_{-\infty}^{t} a(t,s)\lambda n_s ds \qquad \textbf{3-10}$$

Breaking down the equation even further, $a(t,s)$ is the marginal contribution of a vintage $s$ sector to current innovations, given by the following equation:

$$a(t,s) = \delta \cdot e^{-\beta(A_t - A_s)} \cdot (1 - e^{-\lambda(t-s)}) \qquad \textbf{3-11}$$

$\beta$ is the rate at which old ideas become obsolete, thus useless in the production of new knowledge, where $\lambda$ is the rate of diffusion of older ideas into current general knowledge.

Caballero and Jaffe set the marginal contribution of old knowledge to the development of new knowledge as a function of the citation rate. Where $C_{t,s}$ is the number of observed citations by current patents (of year t) of older patents (of year s):

$$a*(t,s) = \frac{C_{t,s}}{S_t \cdot P_s} \qquad \textbf{3-12}$$

Caballero and Jaffe performed estimations using U.S. data on patents and patent citations. By using their model, they characterised the process of creative destruction. The most important findings from the estimations of the citations function $a(t,s)$ were:

- ideas diffuse rapidly, within one or two years
- The rate of ideas' obsolescence has increased from 3% in the 1900's to up to 12% in 1990; and
- the rate $\dot{A}/n$, where $\dot{A}$ is measured in new innovations, has decreased substantially between 1960 and 1990 (almost 30%), thus indicating either reduced spillovers of older ideas of new knowledge (decrease in $\delta$) and/or an increased rate of knowledge obsolescence (increase in $\beta$).

### 3.4.3 Fundamental stocks of knowledge

The majority of reported research and development is expended in areas where the direct contribution cannot be measured. Griliches (1987) states that because a large component of research and development is aimed at final consumer products rather than process innovations, it is only reflected in those productivity measures where producers succeed in appropriating its fruit.

$Y = F(X, K, u)$ is a production function connecting the measure of output to an index of conventional inputs such as labour and capital ($X$), the current state of technical knowledge ($K$) and $u$ which include all other unmeasured determinants of output of productivity. Griliches assumes a Cobb-Douglas production function form of function $F()$.

$$Y = DC^{\alpha} L^{\beta} K^{\gamma} e^{\lambda t + u} \qquad \textbf{3-13}$$

$D$ is a constant, $t$ is the time index, $e$ is the natural logarithm, and $\alpha, \beta, \gamma$ and $\lambda$ reflect the parameters to be estimated. The current level of technological knowledge $K$ is defined to take the following form

$$K_t = a_0 \left[W(B)R_t\right]^{\eta} e^{\mu t + \upsilon} \qquad \textbf{3-14}$$

In line with the primary aim of the thesis, the main point of interest in this equation would be $W(B)R_t$ the current level of technological change. Griliches defines a stock of current and past levels of R&D expenditures, yet warns that the measurement of R&D capital is a very broad concept, perhaps even too broad to be identified. Although the contribution of science to an industry is also probably not measurable, Griliches focuses on the contribution of industrial R&D and formulates an expression for R&D capital. A number of issues do however arise from this:

- R&D processes take time and the current R&D may only have an impact after several years. An assumption regarding the lag structure of the contribution of R&D capital will therefore have to suffice in some instances
- past R&D efforts depreciate and become obsolete. An assumption regarding the period that the knowledge will remain relevant is therefore necessary; and
- the level of knowledge in any one sector or industry is not only derived from the own

R&D investments but also affected by the knowledge borrowed or stolen from other sectors or industries, i.e. spillovers.

It is however vital to take into account that very different types of knowledge exist and that R&D output results are embodied in people, blue prints, patents, books, etc. Griliches believes the option of aggregating these different types of knowledge should also be considered carefully. He argues that aggregation in this case is in no way worse than aggregating national output in GNP, which also consists of al kinds of factors. The lack of a direct measure of R&D output introduces an inescapable layer of inexactitude and randomness in the formulation.

Griliches opts against using patents and publications, as they are only available in a limited range of sectors and industries. He argues that R&D output is largely unobservable and that it would therefore make more sense to treat it as an input than an output.

In Griliches' model the output of a single firm ($Y_i$), depends on the index of the conventional output of the $i$-th firm ($X_i$), its specific knowledge capital ($K_i$) and on the state of the aggregate knowledge in the industry $K_a$.

$$Y_i = BX_i^{1-\lambda} K_i^{\gamma} K_a^{\mu} \quad \textbf{3-15}$$

From this formulation an aggregate of firms' output would result in the following expression:

$$\sum_i Y_i = B(\sum X)^{1-\gamma} K_a^{\mu+\gamma} \quad \textbf{3-16}$$

This provides a framework for reconciling micro and macro results in this area.

*Academic Research*

Using the exact production function formulation employed by Griliches (1987), Adams (1990) uses the methodology by formulating the production function to include stocks of knowledge among the inputs. The analysis aims to measure the relationship between measures of academic science and multifactor productivity growth.

In Adam's model, the stock of knowledge can be measured by the:

- employed scientists and engineers; and
- a stock of papers.

Adams measured the stock of knowledge in different fields of science, using the following formulation:

$$N_{t,f} = N_{t-1,f}(1-\delta) + P_{t,f} \quad \textbf{3-17}$$

$N$ is the stock of knowledge in field of science $f$ in period $t$ or $t-1$. The stock of knowledge from previous periods are depreciating, this is modelled using the parameter $\delta$. $P$ is the number of papers published in year $t$, field $f$. Adams then formulates a knowledge stock of a whole industry as follows:

$$K_{t-m} = \sum_{i=m}^{T} \sum_{f=1}^{F} L_{t-m,j} N_{t-k-i,j} \qquad \textbf{3-18}$$

where $T$ the total is number of years in the analysis, $F$ is the number of scientific fields and $k$ is an additional lag that measures the duration of the search for useful science. The variable $L$ stands for the number of scientists and engineers employed in the sector.

By the expression of the knowledge stock of an industry in the production function as formulated by Griliches, Adams obtains several estimates for the contribution of academic knowledge to productivity growth rate in the USA.

### 3.4.4 Learning curves and the effect of learning on cost

Learning or experience curves have been documented in a wide array of industries. The learning curve arises when workers and firms learn from experience. As experience grows, workers find ways to work faster and reduce errors. Typically, the unit costs of production decreases by a fixed percentage every time that cumulative production experience doubles.

According to Sterman (2000), cost reductions of 10% to 30% per doubling of experience have been documented in the work of Teplitz (1991), Gruber (1992), Argote and Epple (1990). To incorporate a learning curve into the R&D system, an assumption has to be made that any cost reduction is reflected in the price.

Sterman provides the following expression for the effect an increase in experience ($E$ with $E_0$ as initial experience) might have on cost ($C$ with $C_0$ as initial cost):

$$C = C_0 (E / E_0)^c \qquad \textbf{3-19}$$

For a doubling in experience the cost has fallen a fraction $f$ . The expression will consequently be:

$$C = C_0 (1 - f) = C_0 (2E_0 / E_0)^c \qquad \textbf{3-20}$$

Therefore the value of the parameter $c$ can therefore be computed using the following expression:

$$c = \ln(1 - f) / \ln 2 = \log_2 (1 - f) \qquad \textbf{3-21}$$

Thus, for a fraction varying between 10% and 30%, x can vary between (–0.15 to -0.51). The following figure provides a graphical representation of the effect that an increase in R&D knowledge might have on the cost needed to produce R&D output.

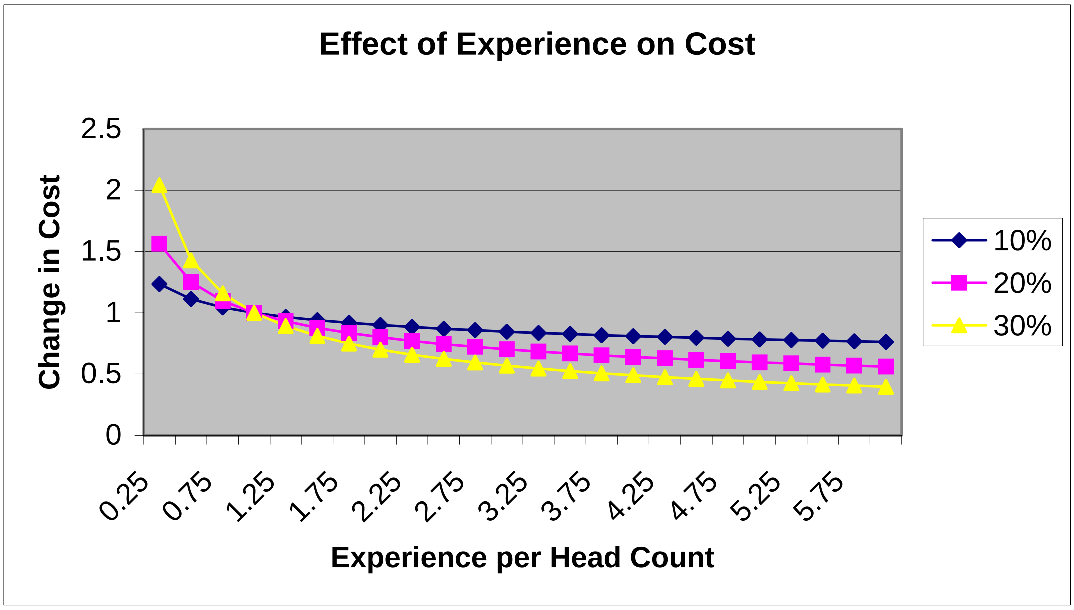



**Figure 3-1: The effect of Experience on Cost**

Learning by doing, R&D and the resulting process improvement are embedded in the organisation's capital stock, worker knowledge and routines. Although this knowledge stock is slow to develop, it also takes time to decay, provided that the human resources remain in the system.

### 3.4.5 Summary

An important and insightful model developed by Cohen and Levinthal (1989) is based on the argument that the R&D process is not merely the creation of new knowledge but that the performance of R&D also results in the development of an absorptive capacity that enables the system to absorb knowledge from the external environment. The absorptive capacity then develops a capacity in the system that ultimately equips an R&D system to create its own knowledge.

This model holds important implications for the dynamic behaviour inherent to the system model developed in this thesis. The model is applied to the firm level and incorporates not only the knowledge spillovers from the firm's own industry but also from outside industries. The model however does not incorporate the effect of decaying knowledge stocks in the system, i.e. forgetting.

Caballero and Jaffe (1993) developed another important model for estimating the growth of knowledge. Knowledge increases in the presence of research labour. Caballero and Jaffe's model again emphasises the important role that human resources play in a system's ability to accumulate knowledge. As the model acknowledges the exponential decay of knowledge in a system as well as the time it takes for the diffusion of older ideas into current general knowledge, it is therefore able to incorporate the flows of knowledge from its creation to the time that it becomes obsolete.

An important aspect of Caballero and Jaffe's model for the purpose of this study is the modelling of the contribution of old knowledge to the development of new knowledge as a function of the citation rate. This approach is also followed in the thesis.

This section also discussed a model developed by Griliches, who defines a stock of current and past levels of R&D expenditures. Although he acknowledges that the contribution of science to an industry is probably not measurable, he focuses on the contribution of industrial R&D and formulates an expression for R&D capital.

Griliches opts against using patents as a measure of R&D output as patenting is only done for a number of industries. The lack of a direct measure of R&D output (knowledge) is a source of inexactitude and randomness in the formulation of the model. The decay of knowledge (modelled as an exponential decay function) is however included in the model. Although the model acknowledges the presence of knowledge spillovers between firms, it ignores intra-industry spillovers of knowledge.

Finally, the section discussed the modelling of learning and the effect of learning curves on the efficiency of workers. Sterman illustrated the use of system dynamics to model learning of human resources in a system. This modelling technique is useful for the purpose of this thesis for modelling the development of tacit knowledge or experience in human resources employed in the South African R&D system.

## 3.5 Models and Quantitative Analysis of Systems of Innovation

This section comprises a brief description and a critical analysis of various quantitative analysis and assessment models of systems of innovation.

### 3.5.1 Comparing performance of NSIs

Niosi et al (1993) proposed studying institutions by means of ratios between basic inputs, i.e. expenditures and personnel, and outputs, i.e. patents, publications, internal reports, innovations and new products, followed by an analysis of their interaction via such variables as size, ownership and control as well as and regional distribution. The following table summarises a number other possible measurements of performance:

**Table 3-2: Measurements for the NSI**

| Performance measure | Explanation |
|---|---|
| Monetary flows (Niosi et al, 1993) | Financing of innovative activities, both public and private |
| Technology flows (Niosi et al, 1993) | Citation analysis in patents, publications, licensing (when available), technological alliances and joint R&D |
| Tacit knowledge (Niosi et al, 1993) | Personnel flows between firms, universities and government laboratories |
| Efficiency (Niosi et al, 1993) | Analysis of patents and publications |
| Openness (Niosi and Bellon, 1994)) | Foreign direct investment in R&D, trade statistics in high-technology, international payments for technological services |

Some people are better than others at performing a specific task. This rule also applies to organisations. Some organisations are thus naturally better at performing some tasks than others. Following this reasoning, Niosi proposes a comparison of organisations with similar missions to measure performance. Niosi (2002) defined two terms when dealing with an NIS's performance:

- the 'x-inefficiency' is the gap between observed performance and existing best performance, i.e. maximum output observed in equivalent organisations; and
- the x-effectiveness is the degree at which institutions attain their organisational missions.

An example of a typical mission for a university would be producing human capital, i.e. graduates.

Noisi stresses the importance of developing meaningful and reliable indicators for innovation. The following table provides possible indicators for measuring NSI performance:

**Table 3-3: Examples of Indicators for NSI performance**

| | Level | Indicators (Benchmarks) |
|---|---|---|
| Effectiveness indicators | University | University graduates as a percentage of new enrolment |
| | University | University publication per university |
| | Industry | Industry patent per industrial researcher |
| | Government policy | Number of firms conducting R&D |
| | Government policy | Number of research universities |
| Efficiency indicators | University | Cost of university graduates |
| | University | Cost of university publications (publications/HERD) |
| | Industry | Cost of industry patents (total industrial patents/BERD) |
| | Government laboratories | Cost of government laboratories' patents |
| Quality of output | All institutions | Citations to patents |
| | All Institutions | Citations to publications |
| | Industry | Number of innovations |
| | Industry | Export of technologically intensive goods and services |
| Flows/synergy | | **Personnel flows among organisations** |
| | | **Knowledge flows** |
| | | Technology transfer |
| | | Technological alliances |
| | | Machinery diffusion |
| | | **Financial flows** |
| | | Venture capital for new high-technology firms |
| | | Government subsidies for R&D |
| | | **Regulatory flows** |
| | | Intellectual property registration |
| | | Legislation on standards |
| | | Anti-trust and cooperative rules and laws |
| | | **Human flows** |
| | | University graduates supply and demand by discipline and institution |
| Ratios and indexes | At NSIs level | GERD/GDP |
| | | Revealed technological advantages |
| | | Input/output macroeconomic ratios |
| | | Trade balances on high-technology goods and services |

Niosi's contribution touches on one of the biggest problems obstructing the analysis of innovation as well as the modelling of innovation systems, namely the availability of indicators. Even where indicators are available, the process of analysing the systems remains difficult.

### 3.5.2 Interrelationships among the elements of the NIS

The model developed by Nasierowksi et al (1999) is a comprehensive causal model of the interrelationships among the elements of the NIS, the first model of its kind in literature. The model contemplates how NIS inputs affect NIS related outputs, from patents of various kinds to citations and publications. These, in turn, are expected to affect technological progress through its effect on productivity.

Nasierowksi et al started out by identifying elements that characterise a country's NIS as well as the interrelationships embedded in the system. The following steps led to the development of this model:

- identifying the elements that characterise a country's NIS
- the variables to measure these elements; and
- interrelationships embedded in each individual system.

The elements of the NIS are defined by organising the various NIS elements into different groups, namely inputs, moderators and outputs.

*Inputs:* these are directly responsible for the present and future development of a country's NIS:

- the current state of the human contribution to the NIS, in quantitative and qualitative terms, through an analysis of the country's R&D employment structure; and
- the country's state and involvement in the development of human resources, through investment in future human capabilities.

The variables measuring the input elements are defined as follows:

**Table 3-4**: **Input variables measuring the elements of the NIS**

| Symbol | Name | Description |
|---|---|---|
| GERD | Gross Domestic Expenditure on Research | A measure of R&D expenditure incurred within a given country during a given period |
| FDI | Foreign Direct Investment | A measure of the increasing importance of foreign sources of technology in the composition of a country's NIS |
| BRD | Degree of involvement in R&D in the private business sector | Ratio of business-to-government expenditures on R&D |
| EM | Employment in technology-oriented programs | Total R&D personnel in country |
| EME | Engineers/scientists in R&D programs | Percentage of EM |
| EDU | Total education expenditures | Percentage of GDP |
| EDUT | Tertiary education expenditures | Percentage of GDP |

*Moderators:* the model provides for moderators, which are considered to have an impact on the relationships between inputs and outputs. These elements influencing the effect can be summarised as:

- prosperity of a nation is dependent on the nation's ability to innovate, thus accumulated S&T capability
- *cultural characteristics* to include the impact that the characteristics of a society has on linkages within the system. This model uses Hofstede's (1991) four dimensions of culture, i.e. MAS, PDI, UAV and IND
- patterns of technological development; and
- *size in terms of people and economic wealth* as a measure of a country's ability to absorb and generate novelties.

**Table 3-5: Moderators measurement variables**

| Symbol | Name | Description |
|---|---|---|
| PPP | Purchasing Power Parity | Proxy of a country's ability to pay for technological progress |
| LIT | Size of a country's literate population 15 years or over | Proxy for a country's past commitment education |
| MAS | Masculinity index | The extent to which the dominant values in society are characterised by assertiveness, the acquisition of money and things as well as indifference to others |
| PDI | Power Distance Index | The extend to which society accepts that power in institutions and organisations is distributed unequally and thus accepts high levels of social and economic inequity |
| UAV | Uncertainty Avoidance Index | A measure of the proclivity to avoid uncertain situations, i.e. the extent to which a society feels threatened by uncertain and ambiguous situations and tries to avoid them by providing greater career stability, more formal rules and believing in absolute truths and the attainment of expertise. |
| IND | Individualism Index | A measure of the proclivity to avoid individualistic attitudes and hence expect others in groups of which individuals are part of family/organisations to look after them. |
| GDP | Gross Domestic Product | A measure of a country's size by wealth, in billions of US$ |
| POPU | Size of country by population | In millions of people |
| LFOR | Size of country's labour force | Percentage of POPU in the labour force |

*Outputs:* the degree of proficiency of the use of inputs and moderators in the generation of technology. Three sets of output are used, namely:

- solutions
- knowledge base; and
- productivity.

**Table 3-6: Output measurement variables**

| Symbol | Name | Description |
|---|---|---|
| PAUS | Patents in the US by residents of a given country | A measure of excellence and importance of the discovery |
| PATE | External patents by residents | A measure of a country's involvement in international business co-operation and export activities |
| PATR | Patents by a country's residents | A measure of the local's effort in the investment in solutions for the internal demands of one's country |
| PATT | Patents by residents and non-residents in the country | A measure of the combined effects of the local and international business community in the country's 'investment in solutions' effort |
| PUB | Publication counts | A measure of the country's ability to create the 'knowledge base' |
| CIT | Citation counts | A measure of the perceived quality by others of a country's knowledge base |
| PRO | Productivity | GDP per employee per hour |

To develop the I/M/O model of an NIS, data from 41 countries were used. The number of possible constructs was decreased considerably through the study of possible interrelationships among the elements of individual NISs.

From the list of 41 countries, the analysis of the data resulted in two consistent patterns. As a result, a binary value was added to the NIS data set to identify the cluster that each of the countries belong to. Cluster 0 countries proved to be more inclined towards technological development and acquisition and than cluster 1 countries. These countries were wealthier, had higher literacy rates, invested more in their human resources and were more likely to attract foreign investments. There was also a higher incidence of business involvement in R&D. It seems that the market size measured by population rather than GDP/wealth determine a country's preferred R&D policies towards its domestic market by favouring local outputs either short term, i.e. patents, or long term, i.e. publications. Cluster 0 countries dominate the generation of outputs, especially in terms of overall quality (PAUS), quantity (PATT), acceptability by others (CIT) as well as ultimate economic reward of increased productivity (PROD).

The I/M/O structures examined each country in terms of its double role as receptor and generator of R&D technology.

As a receptor, the factor loadings suggest the following four characteristics to be the most important:

- *R&D culture*: the following variables are linked to a country in cluster 0:
  - individualistic (INV)
  - highly productive (PROD)
  - high purchasing power (PPP)
  - concerned with the development of the human base (EDU, EDUT); and
  - has longer term outputs (PUB, CIT)
- *short term output activity*, as a measure of the extent to which past R&D investment translates into short-term solutions:
  - local patent activity (PATT); and
  - inside the frontiers (PATR) or outside a country (PATE).
- *quality of output activity* relates to the competitive advantage that wealthy countries (GDP) enjoy in the production of high quality outputs (PAUS); and
- *market potential* provides an indication of a country's ability to consume new technologies in terms of earning potential (LFOR) and educational level of population.

As a generator, factor loadings suggest the following five characteristics to be the most important:

- *innovative capacity*, this deals with the country's ability to generate new technology:
  - high productivity (PROD)
  - purchasing power (PPP)
  - highly educated population (LIT); and
  - a private sector able to invest in R&D activity.
- *investment in future*, representing the investment in human capital (EDU, EDUT) for the future as well as the degree of confidence that the international community portrays in the country (FDI)
- *initiative* considers factor valuing individual decisions making (INV) as well as the

international perception of the country's long-term R&D potential (CIT)

- *patent quality* as the country's ability to generate new technology of high quality (PAUS); and
- *short term output activity* as the country's ability to generate quantities of new ideas and technology (PATT).

This model developed a framework for the analysis of a country's NIS by considering the NIS as a sector of the economy. As a result, elements are characterised according to their roles in the NIS.

### 3.5.3 Innovative capacity

Furman et al (2002) developed a non-descriptive analysis in an attempt to enable a more formalised cross-country analysis of NSIs. The analysis focuses on measuring a country's *innovative capacity*. Innovative capacity in this context is defined as: "National innovative capacity is the ability of a country - as both a political and economic entity - to produce and commercialise a flow of new-to-the world technologies over the long term."

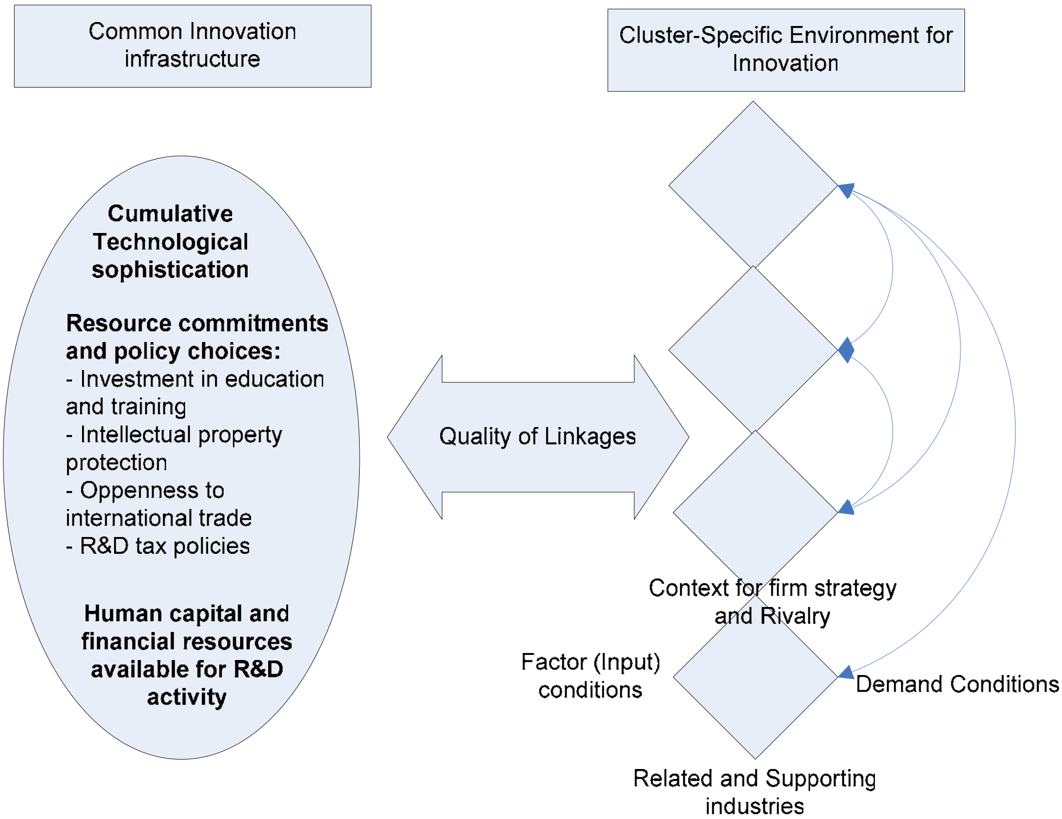



**Figure 3-2: The National Innovative Capacity Framework**

National innovative capacity is not the realised level of innovative output per se but rather reflects more fundamental determinants of the innovation process. This measurement attempts to reflect variation in both economic geography, e.g. the level of spillovers between local firms, as well as cross-country differences in innovation policy, e.g. the level of public support for basic research or legal protection for Intellectual Property (IP).

Where the ideas-driven growth model (Romer, 1990) and the theories of industrial competitive advantage (Porter, 1990) incorporate the role of public policies in shaping the rate of innovation, the national innovation systems literature on the other hand (Nelson, 1993) emphasises the role government plays with policy and specific institutions. As depicted in Figure 3-2, the model is constructed on three building blocks that incorporate the mentioned theories:

- *common innovation infrastructure:* the ideas-driven endogenous growth theory (Romer, 1990) focuses on the economy-wide 'knowledge stock' as well as the size of the R&D labour pool
- *cluster specific innovation environment:* the microeconomic environment influences the firms that ultimately produce innovations. The cluster-based theory of national industrial competitiveness (Porter, 1990) highlights the microeconomic underpinnings of innovation in national industrial clusters. This includes the input supply and local demand conditions as well as the nature and intensity of local rivalry; and
- *quality of linkages:* the strength of the common infrastructure influences the innovative output of the cluster environments and vice versa.

The model employs patent data to evaluate the rate of technological innovation. The authors acknowledge the limitations of using patent data.

### 3.5.4 Flows and dynamics within the NSI

The model discussed in this section was developed at a workshop on S&T indicators held by the Red Iberoamericana de lndicadores en Ciencia y Tecnologia (RICYT) at the Universidad Nacional de Quilmes in Buenos Aires, Argentina. This workshop discussed the topic of measuring stocks and flows of knowledge in a national system of innovation.

CPROST (1997) developed a model to analyse the flows and dynamics within the NSI, based on the following assumptions regarding the characteristics of an NSI:

- firms form part of a network of public and private sector institutions whose activities and interactions initiate, import, modify and diffuse new technologies
- an NSI consists of linkages, both formal and informal, between institutions
- an NSI includes flows of intellectual resources between institutions; and
- an analysis of NSIs emphasises learning as a key economic resource. The analysis also yields that geography and location still matter.

Figure 3-3 (CPROST, 1997) depicts a simplified national system of innovation (NSI). The purpose is however not to define all the elements and their inter-relationships, but instead to paint a picture of the major linkages.

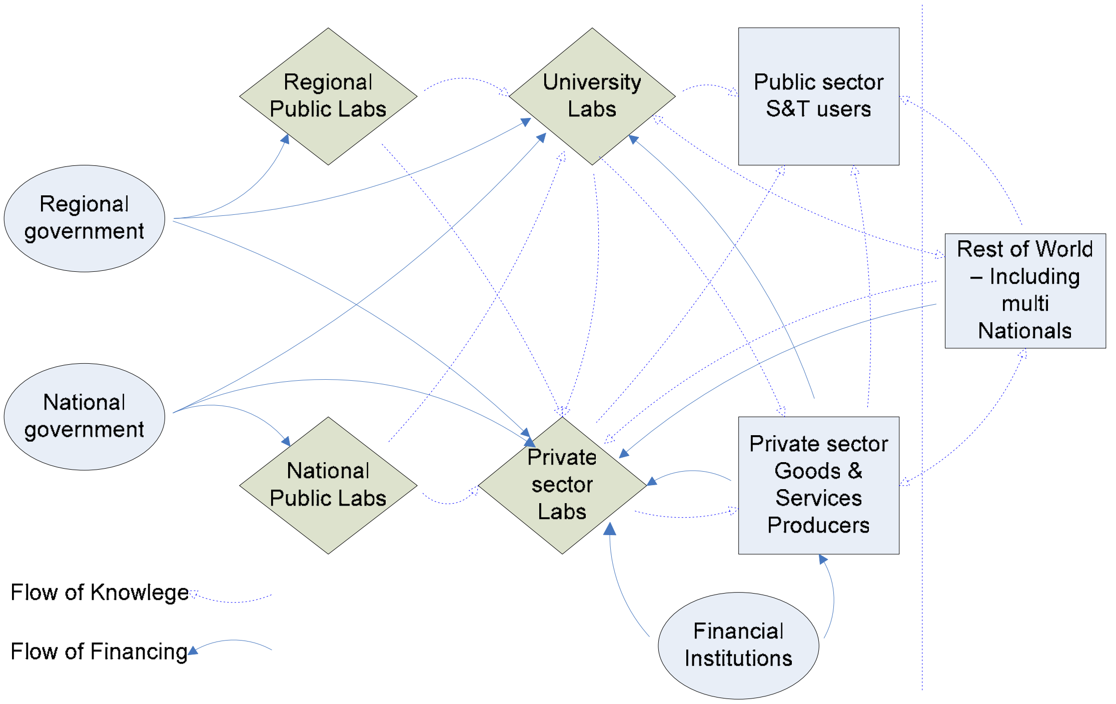



**Figure 3-3: Flows within a simplified NSI (adapted from CPROST (1997))**

This model is based on Edquist's view of the important role that organisations and institutes play in the analysis of the NSI. From insights gained from the work shop it was decided that it was indeed necessary to acquire the ability to measure the stocks and flows of knowledge among institutions, both public and private, and, if necessary, to develop indicators appropriate to this task. Innovation does not necessarily occur only in the private sector, but to date, there has been no procedure offered for assessing and quantifying innovation in the public sector.

During the development of the model, the following indicators were identified as crucial for information on the British Columbia system of innovation:

- investment in knowledge through R&D expenditures in each of the governmental, business and higher education sectors (*Benchmark:* R&D expenditures as a percentage of GDP)
- production and trade of high-technology products (*Benchmark:* revealed competitive advantage by sector)
- output and trade in high-technology services (*Benchmark:* balance of trade in services)
- investment in knowledge through training scientists and engineers, including social scientists and health care professionals (*Benchmark:* ratio of students who are citizens to labour force or population)
- productive use of knowledge, i.e. human capital, through the employment of trained engineers and scientists, including social scientists and health care professionals (*Benchmarks:* trends in real economic growth, mortality and morbidity); and
- census of innovating firms by sector (*Benchmark:* increase rate of the number of innovating firms).

The above led to an attempt to identify the more important linkages in the British Columbia system of innovation for policy analysis, using the admittedly imperfect measure of R&D

funding.

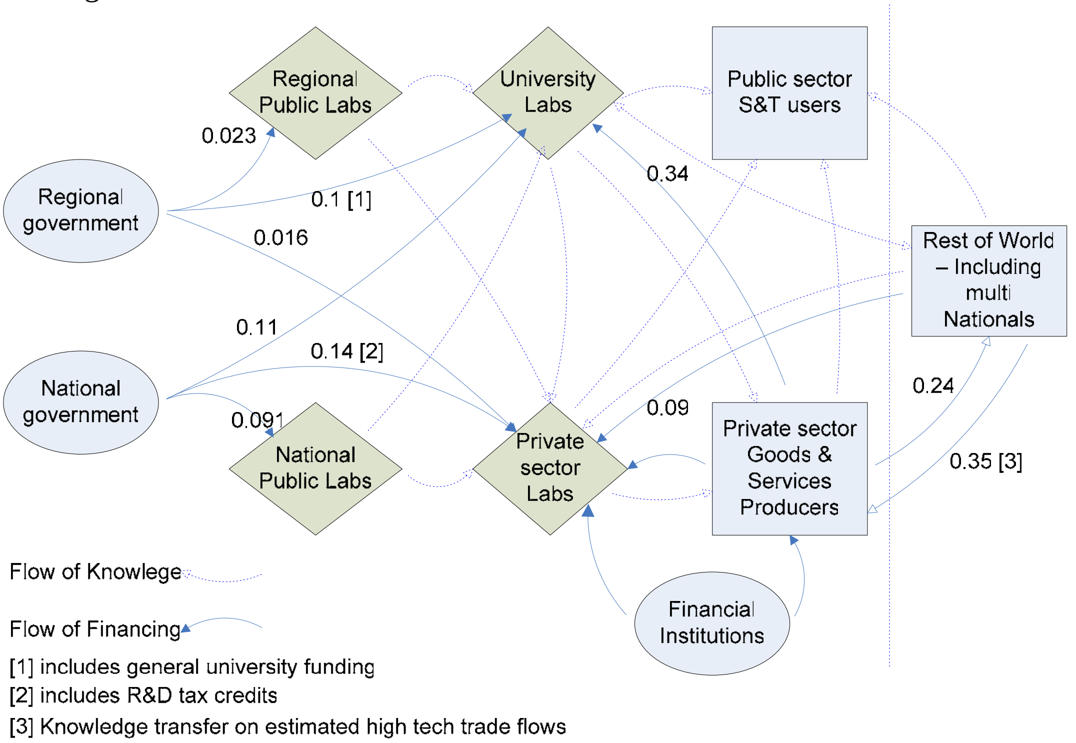



**Figure 3-4: British Columbia system of innovation (adapted from CPROST (1997))**

Using data available from Statistics Canada for 1993, the R&D funding linkages taken from Figure 3-3 are shown in Figure 3-4. The figures are shown as a percentage of gross GDP to facilitate comparisons with other NSIs. In addition to R&D funding flows, estimates of the value of the flows of the knowledge embedded in private sector transactions in intellectual property and high-technology products are also included.

A similar static analysis has been conducted on the South African system of innovation regarding the flow of funds. The following figure depicts the most important flows of R&D funds between the sectors in the South African system of innovation.

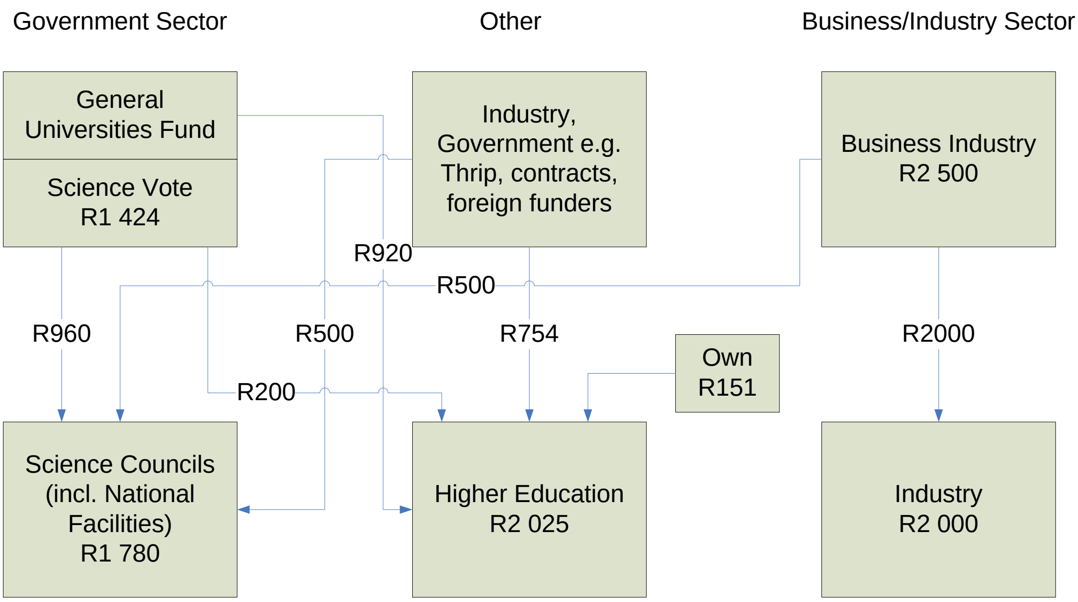


**Figure 3-5: Flows of R&D Funding in the South African System of Innovation**

Figure 3-5 depicts the estimated R&D expenditure (DACST, 2002) for 2000 in South Africa. The three R&D performing sectors together with the main sources of R&D funding are included.

The following conclusions can be drawn regarding the South African R&D system (DACST, 2002):

- R&D expenditure is mainly sourced from the government and industry sectors
- the HES as well as the business and industry sector perform the majority of the country's R&D
- higher education R&D is funded mainly by government, i.e. from General University Funds (GUF), research agency funding, THRIP as well as contracts from government departments and related institutes, such as parastatals. In contrast, the HES contributes minimally to its own research funding, i.e. only approximately 7%, from non-contract income sources, e.g. student fees, interest, donations, etc.; and
- roughly 56% of the funding for science councils is channelled through the parliamentary science vote. The remainder is made up of contributions from industry (29%). government contracts and foreign funders (15%).

The country's total estimated gross expenditure on R&D for 2000 was R5.725 billion. This total excludes military R&D, which, some sources estimate to total approximately R300 million for 2002. The figure also excludes research performed by research NGOs and consultancies.

### 3.5.5 Summary

Interesting conclusions can be drawn from empirical measurement of the modelling studies discussed in this section. Although the purposes differ considerable, all these models portray one common feature: each of these models was developed in an attempt to measure and model innovation from the NSI framework perspective.

Niosi et al (1993) did not develop an empirical model but made some propositions in terms of how the empirical analysis of institutions should ultimately be conducted. His propositions included both studying institutions by means of ratios between basic inputs, i.e. expenditures and personnel, and outputs, i.e. patents, publications, internal reports, innovations and new products, as well as analysing their interaction via such variables as size, ownership and control and regional distribution. The use of ratios of measuring performance is a practical and easy-to-implement approach. This framework does however not contribute to our understanding of the dynamics inherent to an innovation system and is thus considered useful only to compare different systems with each other.

The model developed by Nasierowksi et al (1999) was the first of its kind and established comprehensive causal interrelationships among the elements of the NIS. The model contemplates how NIS related inputs affect the NIS related outputs. It can be concluded that R&D culture, short-term output activity, quality of output activity and market potential are the most important factors determining a country's ability to absorb innovations. The model also concluded that where a country's ability to generate innovations is concerned, the following factors are crucial: innovative capacity, investment in future, initiative, patent quality and short-term output activity. The model attempts to include the development of scientific knowledge, i.e. publications, as well as technology outputs, i.e. patents in terms of innovation outputs. The model structure however relates inputs to outputs through moderator variables and does not provide for complex feedback dynamics in the innovation process.

Furman et al (2002) developed a measurement instrument to enable a more formalised cross-country analysis of NSIs. The analysis focuses on measuring a country's *innovative capacity*, where national innovative capacity is defined as a country's ability to produce and commercialise a flow of new-to-the world technologies over the long term.

The outcome of this model combines the work of Romer, Porter and Nelson for the modelling of technology output measured in terms of patents. This model therefore focuses on measuring firms' innovative capacity and does not provide an analysis for other types of organisations. The model's analysis is therefore only applied to the private sector, which means that it greatly ignores the role of the public sector and the HES. Although the model acknowledges the feedback nature of the ideas produced through the existence of a knowledge stock, no other feedback mechanisms in innovation systems are included.

The section introduced a static analysis of the flow of funds in the British Columbia's NSI, after which a similar model of the flow of R&D funds in the South African system of innovation was introduced. Although these frameworks fail to provide added insight in terms of the high-level flow of funds between sectors and institutions, it is a static analysis and does therefore not include the dynamics involved in the process of R&D or innovation.

It can therefore be concluded that a major drawback of most of the models discussed up to this point was its failure to include dynamic feedback loops in the system's behaviour. As the thesis deals with the development of a dynamic model of R&D in the system of innovation, the following sections discuss the development of system dynamics models of R&D.

## 3.6 System Dynamics Models of R&D and Innovation Systems

Roberts (1978:279) states that once system dynamics work was initiated at MIT, students began to notice potential applications in the areas of technology organisations as well as R&D activities. He argues that this reaction was a natural consequence, given the nature of the methodology's engineering background as well as the initial practitioners. Most practitioners hailed from a technical background and were thus inclined to apply the methodology to areas of interested as well as those field that they were familiar with, which turned out to be R&D. This application produced a heavy concentration of MIT theses on research and development management problems, with spin-off problems in industry and government. Roberts categorises the work done into three main areas:

- dynamics associated with R&D projects
- phenomena associated with the whole R&D organisation, especially resource allocation among projects or areas; and
- interrelationships between the R&D effort and the total corporation or government agency.

In his volume, Roberts (1978:280) stated that up to that specific time, very little has been done in the line of single R&D projects. Repenning (1999) states that since Robert's volume in 1978, the majority of system dynamics models focused on describing and modelling specific development projects, while fewer models were centred on multi-project management of the relationship between R&D function and the rest of the enterprise.

Repenning (1999) reasons that the lack of interest in the R&D function might in part be attributed to the dramatic success enjoyed by single project models. According to Repenning, Pugh-Roberts consulting company used Roberts' approach in dealing with single project dynamics (Roberts, 1964) to help Ingall, a huge shipyard, to settle a multi-million dollar claim against the United States Navy (Repenning, 1999). The same company also developed a huge model for Litton industries encompassing the entire design, development and engineering phases of the DD and LHA shipbuilding programmes. Pugh-Roberts have since become the industry leaders in system dynamics modelling.

Since the vast amount of literature on system dynamics models of R&D deal with single project models, the following section briefly describes some of these models.

### 3.6.1 SD models of single project R&D and R&D on the firm level

In his volume, Roberts (1978) describes an R&D simulation model developed by Weil, Bergan, Roberts (1978) as a management tool to decide on strategy. The model's use is described in terms of the different ways in which R&D strategies can be implemented.

Repenning (1999) lists some influential models of R&D. Abdel, Hamid and Madnick, (1991) developed a model of a single projects R&D system for applications to software development, while Homer's (1993) model dealt with the construction of pulp and paper mills. Ford and Sterman (1998) developed a single project R&D model of the design and development of semi-conductors.

Milling's (2001) product innovation process model depicts the development of new technology by incorporating an evolutionary module of product improvement. This model is applied on a single firm and single product level.

Hilmole, Helo and Kekale (2004) analysed a theoretical model of a start-up technology company as an input-delayed economic transformation process. The purpose of this model is to reach a better understanding of the working of the system where three different parameters are changing, namely R&D productivity, R&D share and budgetary expenses. Qingrua Xu et al (2004) model the motivational aspects of human resources in an R&D company. The company's performance is modelled as a function of competency and incentive.

Moizer and Towler (2004) developed a generic model characterising and capturing the causal feedback structure and performance behaviour inherent to a generic R&D system within a firm. Alternative what-if scenarios are tested on the mode to estimate the effect of R&D resource decisions coupled with changes in market demand.

Hansen, Weiss et al (1999) developed a model aimed at depicting funding allocations within a firm with considerable R&D activities. The issues relating to spending is the ever-present struggle between redistributing profits to investors versus reinvesting in the R&D function. A second decision regarding spending is to decide on the type of R&D expenditure in terms of basic, applied and experimental development. The model uses the system dynamics methodology to illustrate the effect of the allocation of funding to different phases in the R&D process. The model therefore aims to optimise resource allocation in real organisations.

Repenning (1999) states that measured in dollars, single project models have influenced management processes much more than any other type of application within the system dynamics methodology. Acknowledging the gap in the literature as well as the need for models to address multiple project situations, he developed a model for the environment of multiple R&D projects and the allocation of resources between them.

### 3.6.2 System dynamics models of R&D and innovation on a macro level

Up to this point, the R&D models discussed dealt mainly with those developed on either a single R&D project level or on a firm level. These models only provided for R&D processes involved in the development of one or in some case more products within a firm. We can therefore conclude that many system dynamic models of R&D have been developed on the firm level. The question arises: what about R&D on a more aggregated level?

Since this thesis deals with the development of a system dynamics model of R&D on the national level, the following section focuses on models in the literature dealing with R&D and innovation models on a national, regional or industry level. Surprisingly, few system dynamics models dealing with government policy for R&D on a system of innovation level could be found in the literature. The following sections briefly describe and discuss some of the models and a number of findings that resulted from them.

#### 3.6.2.1 Regional innovation system of Jilin province in China

Zhang et al (2004) explore the definition and function of the regional innovation system as well as analyse its framework, operation mechanism and systemic characteristics.

Zang et al state that the system dynamics approach coincides with the regional system of innovation framework. Regional innovation systems are developed on the base of feedback chains existent in the system that ultimately results in a more complex structure within the system, i.e. feedback complexity. The aforesaid therefore indicates to the existence of complex, interdependent relationships between elements in the regional innovation system, of which many have non-linear characteristics.

The model divides the regional innovation system into five subsystems, namely:

- *innovation environment subsystem:* regional innovation resources distribution, regional economy and regional innovation culture
- *government activities subsystem:* activities and functions of government as a unit of institutional innovation
- *enterprise activities subsystem:* activities and economic effects of innovative enterprises
- *research organisation activities subsystem:* activities and effects of research organisations as units of knowledge generation when participating in innovation alliances; and
- *intermediaries subsystem:* functions of intermediaries when providing innovation services and improving regional innovation.

From the analysis, a model with 27 equations and 67 level variables was developed (for the full model, see Zang et al 2004). The model's output and response is gauged by measuring the following four variables:

- *GDP:* the regional macro-economic operation effect as a whole

- *number of intelligent workers:* this is an important resource of innovation that reflects the region's ability to train, maintain and attract talented human resources
- *management benefit of government:* measurement of government working efficiency and of the corresponding ability of the regional innovation system to function; and
- *efficiency of R&D:* a variable reflecting the abilities of research organisations for the co-operation in innovation and industrialisation as well as the intention and conformity of regional technological innovation resources.

The model was used to analyse the development, operation and performance of the regional innovation system in the JiLin province. The model was also used to make policy recommendations to the government regarding the development of the regional innovation system.

The above section therefore concludes that the system dynamics methodology has been implemented successfully in the development of a regional system of innovation. The model was used as an analysis tool to examine the development, operation and performance in the JiLin province in China. The model is extremely relevant to this study as the development of the model illustrates the applicability and usefulness of a system dynamics model of innovation activities on a meta-level. It should also be noted that more accounts of such models exist.

The following section describes a system dynamics model that has been developed to simulate and analyse the long-term investment policies in military R&D in Taiwan.

#### 3.6.2.2 Long term investment in military R&D in Taiwan

As Taiwan progressed from a developing country to a Newly Industrialised Country (NIC), its weapons acquisition policy evolved from the initial foreign weapon acquisition policy to independent R&D. The weapon R&D budget share in Taiwan's major weapon development budget thus gradually rose from 0% to 0.5% of GDP. Taiwan has progressively accumulated sufficient knowledge and experience of the key technologies to develop its own weapon systems. Technological maturity allowed Taiwan to purchase more advanced weapon systems. However, since pressures from the international armaments market forced the weapons acquisition policy back towards the earlier foreign weapons purchasing policy, R&D budget share dropped to below 0.3% of GDP.

Jan and Jan (2000) developed a system dynamics model depicting the effect of long-term investment in military R&D in Taiwan. They believe that R&D should exist for a country to be able to develop or acquire high technology. The investment in R&D capacity comes at a very high cost and accumulates slowly. If not supported, the capacity will vanish quickly. The different R&D purposes, functional demands, and system complexities differentiate the applied sciences in weapon systems R&D technology from those in ordinary civilian industries. Foreign R&D skills cannot be transplanted directly and a nation must be completely self-reliant.

The following stock and flow diagram was taken from Jan and Jan (2000). The model simulation indicates that where key technologists vanish, decades are required to make up for the loss. Reaching a balance between foreign acquisition and self-development therefore proves a long-range strategic problem for Taiwan.

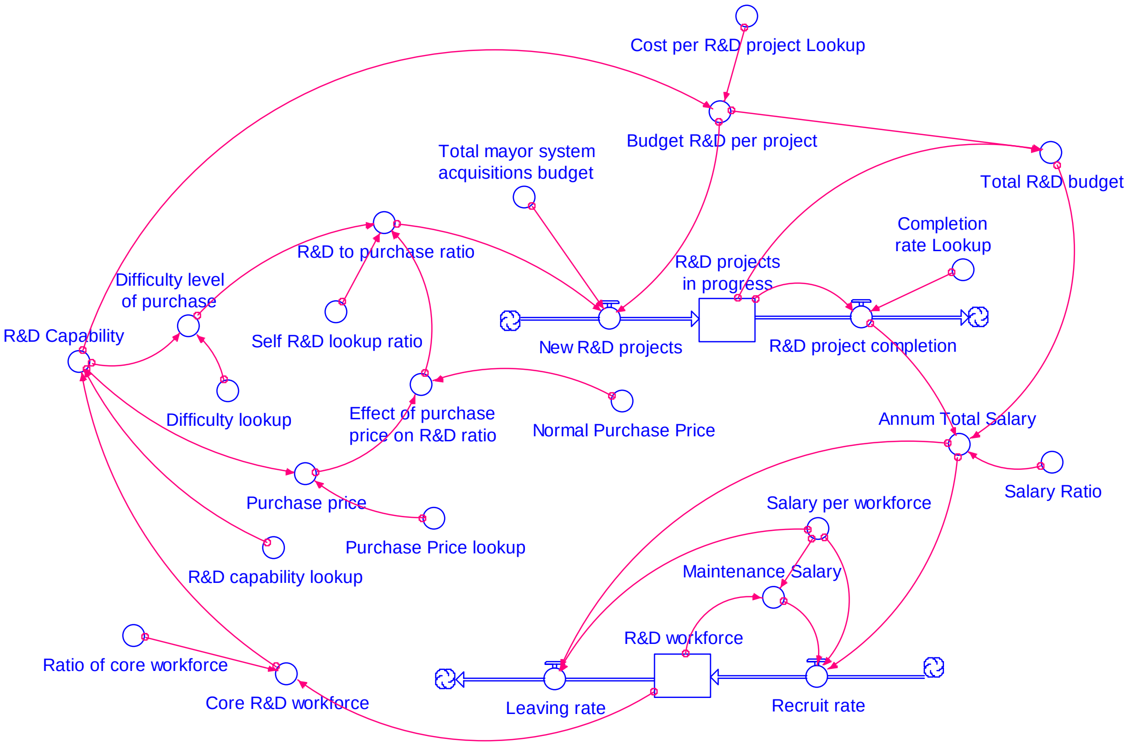



**Figure 3-6: Stock and Flow Diagram from Jan and Jan's (2000) Model**

The Taiwanese experience reveals that R&D capacity is a key factor in weapons acquisition policy making for NICs. Such a capacity is slow to establish and costly to maintain. Inappropriate policies also have the ability to erode such capacity rapidly. This study applies system dynamics methodology to analyse the problem. It assists in examining the characteristics of weapon system development and constructs a dynamic model to improve understanding of the structure of weapon system development. The study also provides a basis for a clearer and broader understanding of future policy making considerations for NICs.

A similar model has also been developed for the South African armament industry (see Buys, 1990).

This section discussed and illustrated the use of a system dynamics model to develop a model of the development of R&D capacity in the armaments industry. Many of the concepts included in the model also apply to general R&D capacity development, an issue that will be discussed in more detail in the model development chapter in this thesis.

The following section describes a system dynamics model developed to simulate and analyse funding decisions in R&D investment in South Korea.

#### 3.6.2.3 Leverage strategy to R&D investment in South Korea

Over the years, the Korean R&D investment institution has made substantial commitments to the expansion of total funding packages awarded to selected national R&D projects. Increases in the dollar amounts of these targeted projects resulted in the stage-by-stage evolution of Korean technologies. What demarcates the Korean national R&D investment institution from its international competitors is the unusually high discrepancy between the total investment stock and consequential research results that have the benefit of international recognition (Park, Oh and Kim, 2004).

To various studies conducted before the system dynamics model was created failed to address these structural issues inherent in the Korean R&D system, especially on the dynamic structure of making funding decisions. Although some extant studies noticed the ongoing decisional problems within the Korean national R&D system, a knowledge gap was identified that no empirical simulation models had been fully developed or tested that could detect underlying structural anomalies rampant in the R&D system.

Park et al (2004) identified three cyclical loops of strategy, structure, and efficacy. These interact continuously with each other to produce both intended and unintended outcomes of national R&D projects. The causal loop diagram is depicted in Figure 3-7.

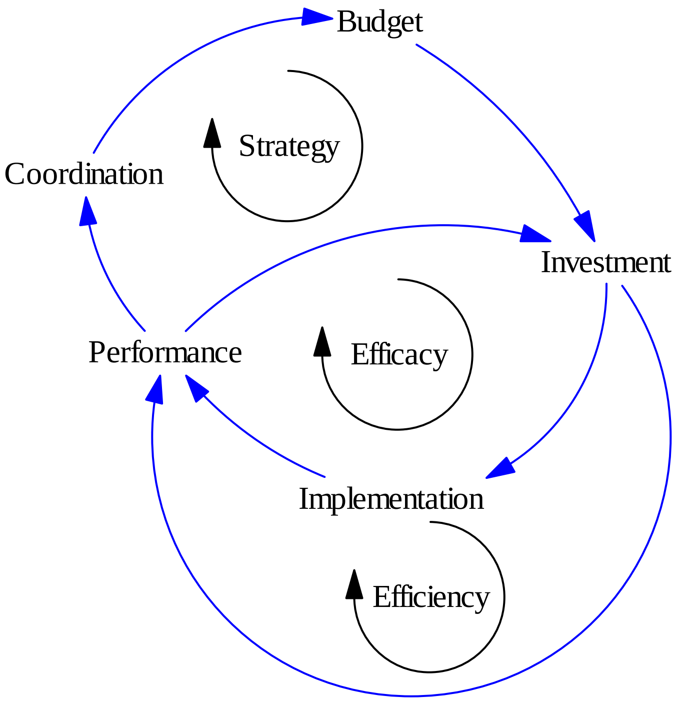



**Figure 3-7: Three Cyclical Loops of Strategy, Structure and Efficacy (Park et al, 2004)**

Research performance is examined both quantitatively and qualitatively. The quantitative option simply implies count all completed projects within a given deadline, while qualitative measurement relates to researchers' attitudes.

The number of completed projects measures research performance by researchers' actual attitudes. The actual attitudes concept incorporates both will and real activity levels held by researchers and are expressed in terms of the level of confidence on research performance held by researchers multiplied by their actual research activities. It is assumed that the level of confidence is correlated with researchers' positive attitudes toward their projects. The efficacy loop has the following stocks and flow structure:

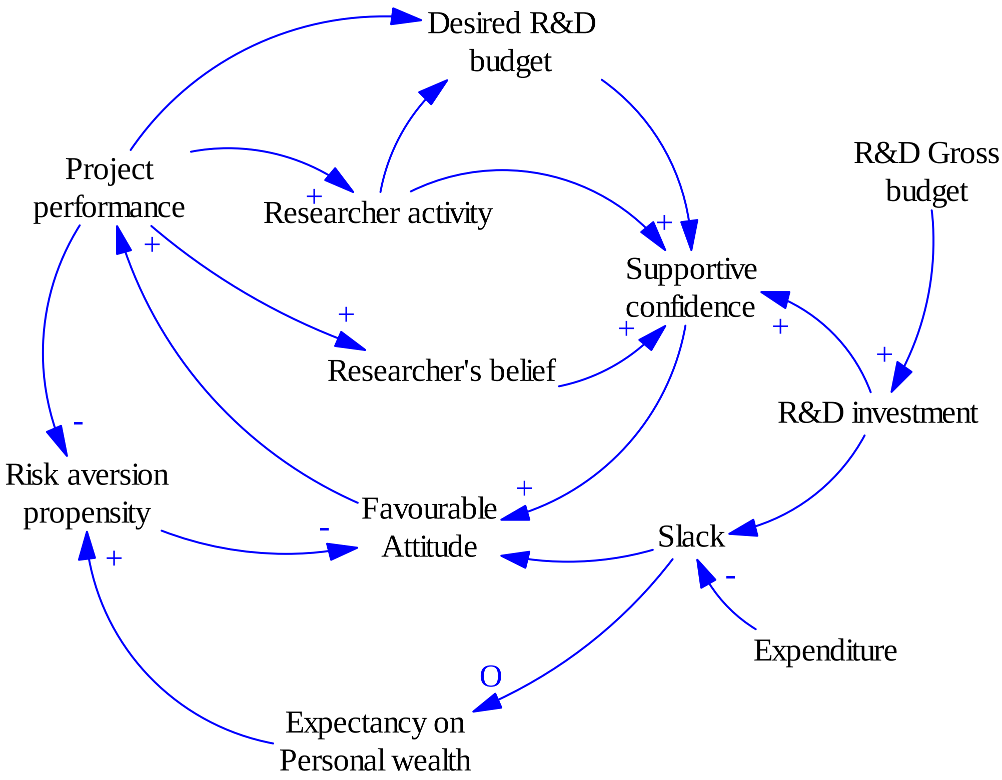



**Figure 3-8: The Efficacy Loop (Park et al., 2004)**

NIS projects can be classified into competency building programmes and strategic technology development programs.

Capacity building programs include foundational science, human resource development and short-term projects. It is thus assumed that knowledge accumulation will grow exponentially past a specific tipping point, although this will not be visible in early stages.

Strategic technology development programmes usually include long-term projects for developing strategically targeted new technologies, although they quickly adapt to changing environments. It is assumed that the finished results of each project might be extremely visible, although new technologies can easily become obsolete when the market is saturated. In the long run, strategically developed technologies disappear from the market. Strategically developed technologies maintain linkages between different dimensions of technologies. In a linear relationship between stages of technological development, basic technology serves as a basis for application and add-on technologies. Absorptive capacity determines the learning capacity and how successful it is applied in the domestic environment.

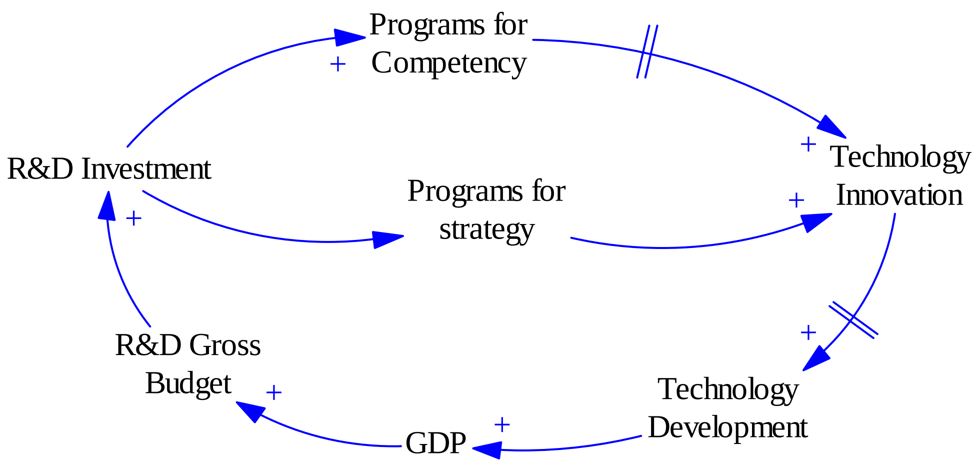



**Figure 3-9: The Efficiency Loop (Park et al., 2004)**

The model simulation runs yielded output which showed that emphasis on application and 'add-on' or developmental technologies resulted in long inter-stage temporal gaps, although their short-term economic benefits were obvious.

In a similar vein, myopic investments in specifically targeted technologies in strategically designed R&D projects led to decreasing levels of absorptive capabilities, whereas far-sighted investments brought about adversary results. Finally, it was found that an initial investment package did not have significant impact on the level of researcher efficacy, which predicts a more complex dynamics of researcher motivation structures than usually assumed.

The above section therefore holds that a system dynamics model explaining the influence of R&D investment in the South Korean innovation system has been developed. This model simulates the effects of different types of R&D investment decisions on the R&D capacity of South Korea. It should also be noted that many qualitative aspects, such as 'researchers' beliefs', etc. are included in the model. The use of unquantifiable concepts in system dynamics models has unleashed much criticism in the approach.

### 3.6.3 Summary

This section thus describes how system dynamics models have been implemented to foster a better understanding of dynamics in R&D systems. Models developed for R&D on the project level as well as on the firm level were scrutinised.

The second section focussed on existing models developed for the analysis of system dynamics models of R&D on the macro level. These models clearly indicated that R&D investment plays a crucial role in the development of R&D capacity in an innovation system. This was especially clear in the model developed for the Taiwanese armament industry as well as the model for R&D investment in the South Korean R&D system.

The section therefore concludes that the system dynamics methodology has been employed previously for the implementation of an R&D model of a system of innovation. Zhang et al (2004) specifically comments on the use of the system dynamics approach within a system of innovation framework. The prevalence of feedback chains in innovation systems cause structural and behavioural complexities results in non-linear interrelationships between elements in innovation systems.

## 3.7 Models of the South African System of Innovation

The following sections focus on a number of models and accounts that have been developed especially for the South African system of innovation.

### 3.7.1 The technology colony framework

South Africa has been described as a technology colony [De Wet, 2001], i.e. countries where the NSI is so poorly developed that it is dependent on foreign technology. The product life cycle model for the technology colony is depicted in Figure 3-10.

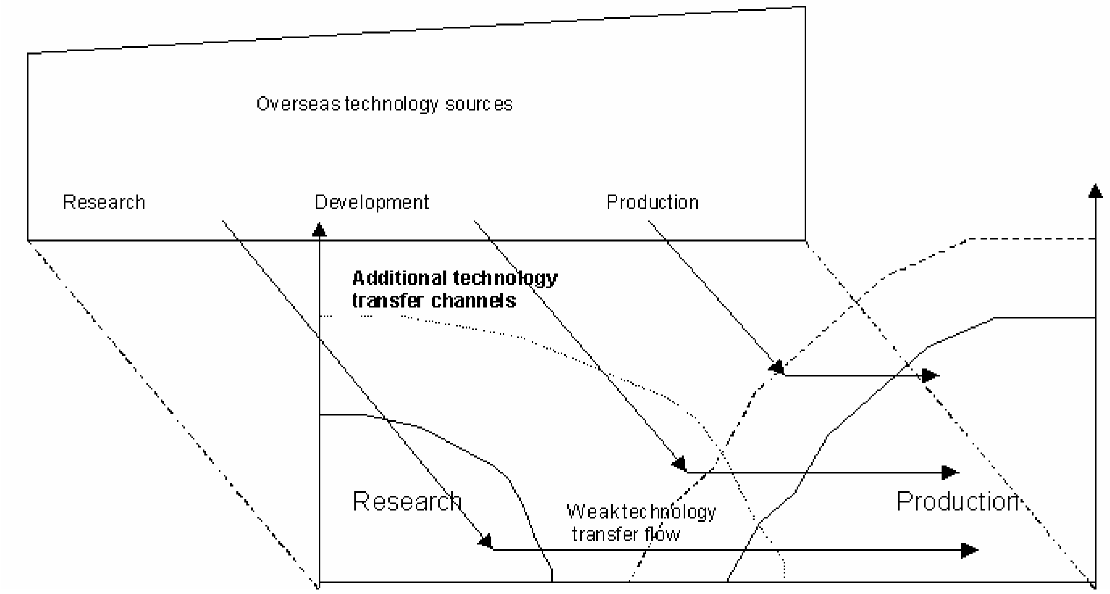



**Figure 3-10: The Product Life Cycle with the Effects from Backwards Integration**

A technology colony has the following features:

- the predominant industrial business activity is the manufacture and 'trade-in-final-products' end of the products lifecycle
- a small group of activities exist in the research end of the lifecycle. These are the R&D activities of tertiary education institutions; and
- there is a large flow from the developed world into the colony. This occurs in the form of licensed product designs, processes, subassemblies and final products, often implemented through a subsidiary or multi-national firm.

Although there is only a small insignificant flow from the R&D sector to the industrial sector, there is a certain degree of communication between local and foreign R&D institutions.

### 3.7.2 The system theory model of innovation

Buys (2001:2-3) proved that by reversing the linear model of innovation, technology colonies could attain technological independence. By applying the concept that the NSI consists of a set of interacting subsystems, Buys (2001:8-11) developed a five-stage process of backwards integration. He used his system theory model of innovation to characterise the South African system of innovation (Buys, 2004).

Buys (2001) proposed that the NSI can be defined to comprise the following subsystems:

- research
- technology development
- new product/process development
- product/process improvement
- the production and manufacturing; and
- the distribution, marketing, sales and services.

With De Wet's model of the technology colony in mind (De Wet, 2001), Buys went one step further by developing a model where a NSI is viewed as a set of functional subsystems interacting with each other and with foreign systems of innovation by transferring products, services, information and knowledge as depicted schematically in Figure 3-11 (Buys, 2002).

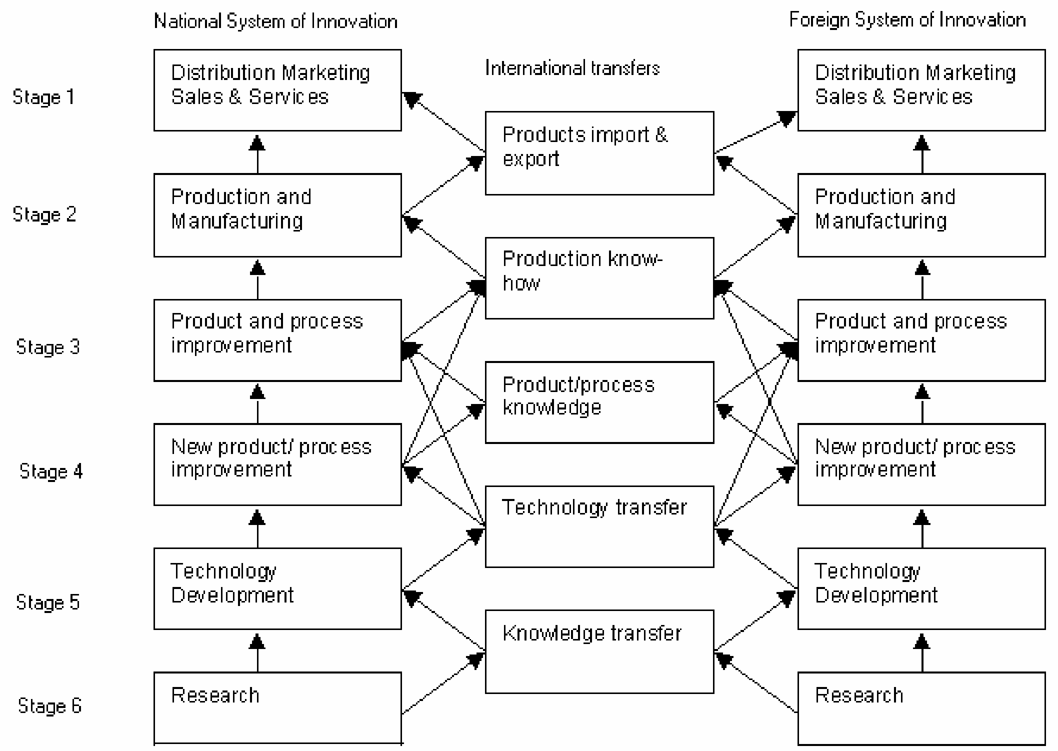



**Figure 3-11: System Theory Model of the NSI**

Buys applied the system theory model of innovation to the backwards integration process and identified five stages of industrial development:

- stage 1: local distribution, marketing, sales and after sales services as well as foreign products and services
- stage 2: local production and manufacturing of products and services using foreign process technology
- stage 3: local improvement of products and processes using foreign technology

- stage 4: local development of new products and processes using foreign technology; and
- stage 5: local technology development.

Buys classified South Africa to be in stage 3 of the backwards integration process. The advantages of being a technology follower might include that firms take even less time and spend less money to deploy innovation like in the case of Japan. Follower countries should however aim to progress through the stages of backwards integration to build competitive capabilities for the future.

### 3.8 Shortcomings of Current approaches – Knowledge Gap

The research survey concludes that there exists a vast literature of econometric models of R&D production as well as the economic contribution of R&D on a country's economy. The literature surveyed produced a small sample of a much larger literature on models formulated to explain productivity increases as a result of R&D and spillover effects. Many of these models were developed using the econometric approach where a number of inputs to a production function are identified, after which it is estimated to fit a curve. None of these models were developed from an NSI framework perspective. In general, these models thus lacked the inclusion of the feedback dynamics of innovation from a system perspective.

In 2002, Carlsson et al (2002:236) stated that the empirical analysis of studies carried out on NSIs involved mainly static data. Since then, not much progress has been made. This complicates the comparison of nations' relative positions over a longer time period. Another shortcoming of the empirical analysis of NSI studies is that many tend to be descriptive and consequently fail to capture the system's dynamic behaviour.

The lack of dynamic models is also noticed in the models dealing with the South African system of innovation. These models are successful in what was set out to accomplish, thus describing the character of the system and deriving strategies from the descriptions. These models are however not equipped to capture the dynamic characteristics of the system and to simulate the long-term effects of changes to the system. These models also fail to provide a dynamic account of the effect of R&D investment on R&D activities within the South African NSI.

A number of models of systems dynamic models of R&D on an aggregate level were discussed. The models indicated that system dynamics can be implemented to build a useful model of R&D and innovation on a macro level. Although system dynamics has been used to formulate strategy within the South African S&T system, no model of R&D output as a function of long-term effects of investment in R&D is presently available for South Africa.

A knowledge gap is therefore identified from the models discussed in this section, thus none of these models describe the systemic nature, interdependence of elements and the prevalence of feedback loops in the R&D function within a NSI framework adequately.

# 4 RESEARCH DESIGN AND METHODOLOGY

## 4.1 Purpose and Outline of the Chapter

The purpose of this chapter is to explain and document the research methodology and testing strategy followed in the research project.

Although the primary data gathering methodology is introduced, the documentation process thereof is not recorded in this chapter. Please refer to Chapter 6 for a detailed account of the Delphi study performed.

The chapter discusses and describes the research design, after which background information and the origins of the system dynamics methodology are provided. A section is allocated to a detailed description of the methodology. The most important strengths and weaknesses of the system dynamics methodology are explored and its particular suitability for this research project is discussed.

This chapter also analyses the model building process as well as the testing and validation strategy followed.

## 4.2 Research Design

### 4.2.1 Design description

The type of research undertaken in this project is a theory/model building study. Mouton (2001:176) describes such a study as "Studies aimed at developing new models and theories to explain particular phenomena."

Scientists employ models and theories in an attempt to explain observed phenomena in the world. Science can simply not progress without these models and theories. A model is a set of statements aiming to represent a phenomenon or set of phenomenon as accurately as possible. Good theories and models (Mouton, 2001:176):

- provide causal accounts for the world
- allow us to make predictive claims under certain conditions
- bring conceptual coherence to a domain of science; and
- simplify our understanding of the world.

This research project proposes a dynamic model for R&D in the NSI. The applicability and validity of this model depends on the quality of causal assumptions made and the accuracy of the structure of the model.

### 4.2.2 Design classification

The study is empirical in nature. Secondary numerical and textual data is thus used in developing the model. In some instances, databases were analysed and data was extracted.

The structure of the model is derived from secondary textual data. The method followed in deriving the model for this study is therefore chosen to be deductive reasoning, one of the most powerful methods of deriving models and new theories.

One of the main problems usually encountered with the development of system dynamics models is the availability of reliable time series data. This study is certainly no exception. The author did however go to exceptional lengths to ensure that the most accurate and reliable data was used for the empirical testing and ultimately for underpinning of the model.

Primary data was gathered by means of a Delphi study, a study employed to gather data and opinions on the following issues:

- appropriateness of indicators used to measure R&D output in the study
- alternative indicators to measure R&D output in South Africa; and
- the main issues that will threaten the South African R&D capacity in the following 20 years (future trends).

The Delphi study is discussed in detail in Chapter 6.

The following section describes the modelling methodology followed in the thesis in greater detail.

### 4.3 The System Dynamics Methodology

The system dynamics methodology aims to analyse complex systems and problems, using computer simulation software. System dynamics originates from the 1960s, when Jay Forrester created a methodology for analysing complex systems to aid and improve decision-making and policy formation (Meadows et al, 1974). This methodology could also be used to include relevant cause-effect relationships, delays and feedback loops in complex system to account for their unexpected behaviour.

In July 1970, the executive committee of the Club of Rome attended a seminar presented by members of the System Dynamics Group at MIT. The committee was tasked with determining whether the system analysis techniques developed at MIT could provide new perspectives on the interlocking complexity of costs and benefits inherent in continued physical growth on a finite planet. Forrester introduced a preliminary computer simulation model known as World2 at The Club of Rome meeting. The model specified important relationships among population economic output and environmental constraints (Meadows et al, 1974).

Using system dynamics modelling, Forrester demonstrated how simple solutions often had unplanned and unwanted effects. He used the methodology to emphasise the importance of clarity of purpose before intervening in a system to correct a defined problem, issue or undesirable effect. Forrester ultimately contributed a method through which problems can be solved with more sophisticated levels of analysis (Forrester, 1961).

The four grandparents of the system dynamics methodology are computer technology, computer simulation, strategic decision-making and feedback thinking. It is indeed a fortuitous mix, especially since an engineer's notion of feedback connects seamlessly with the circular causal complexity that strategic thinkers encounter (Coyle, 2000).

In a 1956 paper, which is known today as one of the definitive paper of the field, Forrester (2003) describes the new developments that ultimately enabled him to develop the system dynamics methodology:

- the use of servo-mechanisms and their extensions into complex military weapons systems gave an impression of the importance of inertia, elasticity, storage and delays in determining the stability of complex systems
- the use of differential equations by engineers to describe time dependent systems. The use of differential equations in closed-cycle systems was extended to the theory of sampled data systems
- electronic digital computers developed to a stage where routine processing of numbers were cheaper than doing it by hand; and
- the art of computer simulation models were developed to model systems at an accelerated time scale.

Forrester envisioned an enhanced modelling methodology, one that would enable modellers to model complex systems, such as national economies and industrial firms, more accurately:

> "*I am very certain that the model that now become possible will be effective and of great importance in understanding and managing the individual industrial firm. With respect to the national economy as a whole, I expect the model that can be constructed in the next five years to be many times better than those of the past*." (Forrester, 1956)

Roberts (1978:1) defines system dynamics as the application of feedback control systems principles and techniques to managerial, organisational and socio-economic problems.

System dynamic models are essentially simplifications of reality based on the analyst's understanding of the system and assumptions made regarding expected behaviour. System dynamic modelling in management sciences proves to be an extremely useful tool. The approach indeed proves an excellent tool to assess a system's ability to adjust to change and to test new decisions that have to be taken. System dynamics modelling does however not guarantee accurate prediction of future behaviour. Instead, it is more powerful in increasing the understanding of behaviour and identifying expected trends related to changes in the system (Botha, 1997).

Coyle (1996:10) documented the following thorough description of system dynamics:

> "*System dynamics deals with the time-dependent behaviour of managed systems with the aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policies through simulation and optimisation*".

System dynamic models are mainly used for:

- policy testing (Forrester, 1961)
- what-if scenarios (Morecroft, 1988); and
- policy optimisation (Kleijnen, 1995).

Forrester provides an explanation of his intentions with the methodology as well as how it will enhance modelling techniques when compared to other economic models (Forrester, 1956, 2003). The following section thus summarises a number of the distinct advantages of using the system dynamics methodology as stated in Forrester's paper of 1956. The majority of these advantages are still applicable today.

### 4.3.1 Arguments for using the System Dynamics methodology

*Dynamics structure:* system dynamics allows modellers to include sequence of events in the model structure.

Time delays can be incorporated in the simulation of the system. These do however not refer to the occasional time-shift incorporated in some economic models to obtain a 'lagged' variable for correlation purposes. Instead, these delays refer to an organic delay in one of the flow channels in the model, e.g. the time required for processing an order for goods.

System dynamics also allows the modeller to include reservoir effects into the model. A reservoir effect can be explained as the build up of a level of which the effect is only seen later, e.g. the level of interval between an innovation being considered a luxury versus a necessity.

Lastly, system dynamics allows the modeller to connect the flow of different resources to each other, e.g. the flow of human resources into and out of the system is connected to the flow of tacit knowledge and skills through the system.

***Information flows and decision criteria:*** explicit recognition of information flow channels and information transformation is possible. Many economic models are constructed on the economy's external symptoms. System dynamics however allow models to be constructed on the basic processes included in the system. The modelling methodology also allows for the inclusion of the system's extended history as well as how people might have been conditioned by it.

***Differential equations*** seem to be better suited to describe an economic system's behaviour than the algebraic equations often used in economics. Delays, momentum, elasticity, reservoirs and acceleration are the fundamental quantities differential equations have been developed to describe.

System dynamics allows models of ***much greater complexity and completeness*** than many economic models. A multitude of variables can be included in models with much more ease. The labour involved in the step-by-step solution of differential equations for one single solution is much less than solving a set of algebraic equations in the corresponding set of variables.

Forrester (1968) believes that "most dynamics behaviour, especially in social systems, can be represented by models that are non-linear and so complex that analytical mathematical solutions are either impossible or extremely complex to develop. For such systems, the simulation process of using step-by-step numerical solutions is available."

***Empirical solutions:*** explicit solutions are impossible with the system dynamics approach. Solutions are generated through various assumptions about the model behaviour to changes in constants, individual values of variables.

Simulation modelling is therefore not a general solution. It also does not provide all possible behaviour patterns. Simulation modelling does however provide the time history of system behaviour corresponding to the coefficients and initial conditions whose numerical values were selected. Different conditions in a system can be tested by repeating full step-by-step computation of a system's time response.

The above section therefore concludes that the systems dynamics methodology is a suitable tool for modelling complex systems and systems with feedback complexity.

The following section provides more insight into the methodology itself as well as the different stages and steps of modelling systems.

## 4.4 The Modelling Process

### 4.4.1 Background on the modelling process

Rubinstein and Firstenberg (1995:161) defined a process for the development of a model. To achieve a simple high level of abstraction, the following fundamental steps must be followed:

1. establish the purpose of the model;
2. list the possible elements, i.e. observations, measurements and ideas, however remote, that may relate to the purpose;
3. select those elements listed in step 2 that are relevant to the purpose of step 1;
4. aggregate elements that can be chunked together by virtue of their strong structural, functional or inactive connections between them. This can be described as a process of classification; and
5. repeat step 4 several times until a model consisting of seven elements, aggregated into approximately two chunks emerges;

This process can be repeated by sub-aggregation of each chunk in step 5.

The generic process discussed above is also used when developing a system dynamics model. The development of the system dynamics model is an iterative process ((Coyle, 1996), (Sterman, 2000)). The modelling process, which is also followed in this study, is a continual process of formulating hypothesis, testing and evaluating formal and mental models.

Various researchers have aimed to organise the modelling activities, varying from three to seven different stages, each using a different set of arguments:

**Table 4-1: Steps and Stages in the System Dynamics Modelling Process**

| Meadows and Behrens (1974:5) | Roberts (1983) | Sterman (2000) |
|---|---|---|
| General description of the problem observed | Problem definition | Problem articulation |
| Precise specification of model's purpose | | |
| Definition of time horizon | | |
| Identification of major elements to be included | System conceptualisation | Dynamic hypothesis |
| Postulation of model structure | Model representation | Formulation |
| Estimation of parameters | | |
| Evaluation of model sensitivity | Model behaviour | Testing |
| | Model evaluation | |
| Experimentation and simulation | Policy analysis and model use | Policy formulation and evaluation |

Although the way in which researchers group the main activities of developing a system dynamics model differs, the researchers remain consistent on the activities considered important in the process.

### 4.4.2 Modelling steps followed in this thesis

This research project followed the iterative steps as described by Sterman (2000) in his book, entitled Business Dynamics.

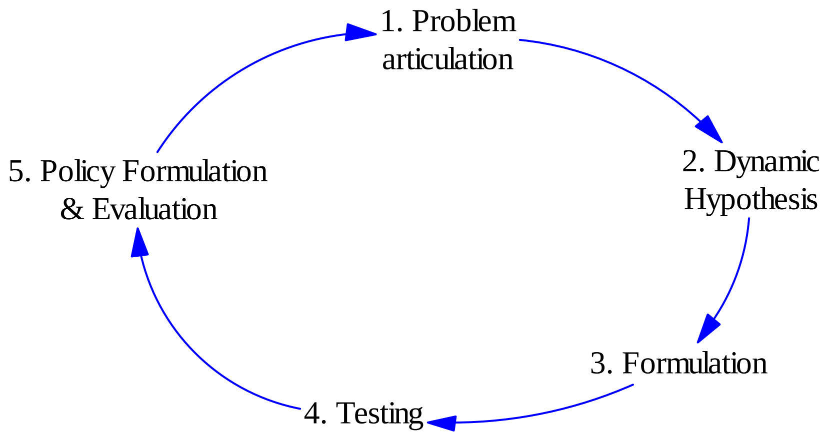


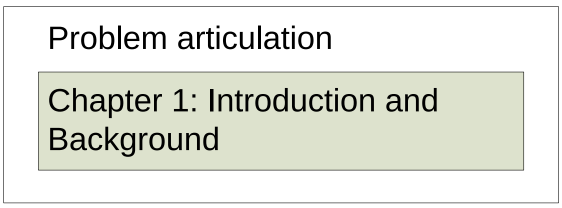

**Figure 4-1: The Modelling Process is Iterative (Sterman, 2000)**

The following sections depict a modified version of the five steps applied in the development of the system dynamics model of R&D activities in the South African NSI. Although the process was very much an iterative one, only the final outcome of each stage is documented. The sections also describe the methodological steps followed in the thesis as well as the chapters in which the phases are documented in the thesis structure.

### 4.4.3 Problem articulation

| |
|---|
| **Background of system:** What is the background of the development of the R&D system in South African?<br>**Research problem:** What is the problem researched in the thesis and why is it a problem? |

This study acknowledges the problem articulation as the foremost step in the modelling process. A clear purpose for the model is therefore the vital ingredient for a successful modelling study. To ensure that the model developed is useful, a specific problem should be addressed. All useful models have one common characteristic: it simplifies reality, thereby easing comprehension. A clear purpose therefore goes a long way in clarifying the elements that should be included in the model. The art of model building lies in the knowledge of what to include, and more importantly, what to exclude. The purpose of the model acts as the logical knife.




**Problem articulation**

Background on SA R&D system
Problem description and articulation
Research question formulation
Rationale of the Thesis

**Figure 4-2 Problem Articulation**

The model's problem articulation is documented in Chapter 1. A brief history of the development of the South African R&D system is also discussed. The chapter illustrated that the system has been developed over decades up to the point where it emerged as the relatively sophisticated R&D system it is today.

### 4.4.4 Formulation of the dynamic hypothesis

**Key variables:** What are the key variables and concepts to be considered in developing a conceptual model of an R&D sector?
**Initial hypothesis generation:** Which current theories around generating and creating knowledge and dynamics are included in R&D and innovation systems?
**Endogenous focus:** Formulate a dynamic hypothesis that explains the dynamics as endogenous consequences of the feedback structure.
**Mapping:** Develop maps of causal structure based on initial hypotheses and the elements important for developing an R&D system's dynamic behaviour.

The dynamics hypothesis is a theory that explains how the system developed its current observed behaviour. The hypothesis is dynamic, since it provides an explanation of the dynamics characterising the system in terms of the underlying feedback as well as the system's stock and flow structure.

A thorough literature study was conducted to scrutinise the existing body of knowledge and to identify the vital elements for inclusion in an R&D system model.

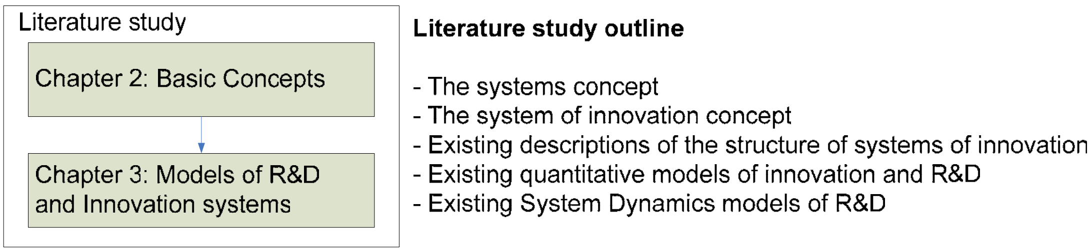



**Figure 4-3 Research on Current Theories of R&D and Knowledge Creation**

The structure and important elements for inclusion in a model was researched and documented in Chapters 2 and Chapters 3. The knowledge obtained in the literature study was applied in developing the system dynamics model. During this development phase of the model building study, an endogenous explanation is provided to explain the dynamics of the system generated as a result of interactions of the elements important for inclusion in the model.

To simplify the task of developing a model for the South African R&D system, a basic building block or a generic model of an R&D sector was defined and developed. The approach followed was aimed at creating a generic model of an R&D performing sector, based on the theoretical principles of the performance of R&D, i.e. the creation of knowledge.

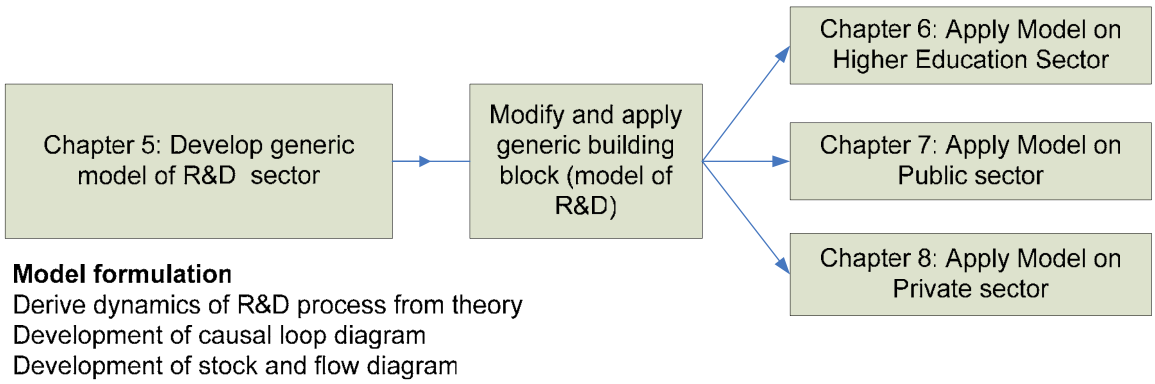


**Figure 4-4: Application of the Generic Model on R&D Performing Sectors in SA**

Although there are some similarities in the development of new knowledge and the specific types of resources in R&D performing sectors, they are also unique in many ways. The generic model was therefore modified to suit the specific and unique structures of different R&D performing sectors within the HES as well as public and business R&D sectors of the South African NSI.

In aid of the communication and documentation of the model boundary and structure, causal loop diagrams as well as stock and flows structures were developed to map the causal links between variables.

### 4.4.5 Model validation and evaluation

*Formulation of the simulation model*

**Specification** of structure and decision rules
**Estimation** of parameters, behavioural relationships and initial conditions
**Tests** for consistency with the purpose and boundary

After the dynamic hypothesis was developed, it was applied to the three R&D sectors in the South African system of innovation. The application of the generic model on the three sectors generated a wealth of insights.

The data gathering is documented in these chapters. The trends observed from the data gathered, resulted in the model being modified accordingly. While the basic feedback structure remains, the indicators used and the specific policies in the sector contribute to some structural changes in the model.

*Testing*

**Comparison to reference modes**: Does the model reproduce the problem behaviour adequately for your purpose?
**Robustness under extreme conditions**: Does the model behave realistically when stressed by extreme conditions?
**Sensitivity:** How does the model behave when given uncertainty in parameters, initial conditions, model boundary and aggregation?

**See Section 4.7 for a detailed discussion on the testing strategy followed in this research project.**

Testing the model comprises much more than only a simple replication of historical data. Tests were conducted on the model to ensure dimensional consistency, sensitivity of the model in terms of policy recommendations as well as uncertainty in assumptions.

The model was also tested for extreme conditions that might not even occur in the real world. These tests are vital tools for identifying flaws in the model.

*Policy Design and Evaluation*

**Scenario specification**: What environment conditions might arise?
**Policy design:** What new decision rules, strategies and structures might be tried in the real world?
**"What if…."** analysis: What are the effects of these policies?
**Sensitivity analysis**: How robust are the policy recommendations under different scenarios and given uncertainties?

**Interactions of policies:** Do the policies interact? Are there synergies or compensatory responses?

These model development phases have been documented in the following chapters:

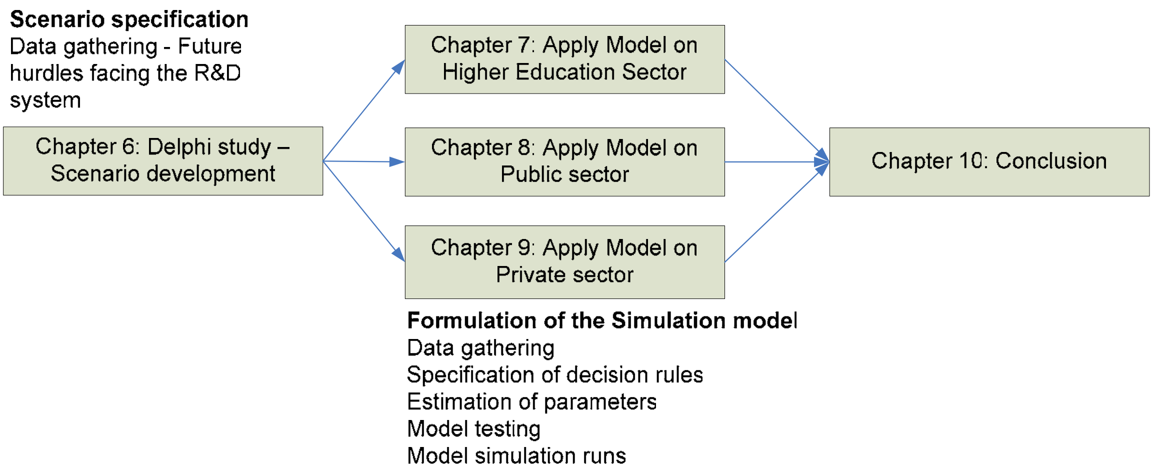



**Figure 4-5: Structure for the Documentation for Model Validation and Evaluation**

Conclusions drawn from the Delphi study was used to develop a selection of scenario tests that, in turn, were run on the system models developed in Chapters 7 to 9.

As a reasonable measure of confidence was developed in both the model's structure and behaviour, it was used to design and evaluate policies for improvement. In some instances during the policy design phase, the process entailed far more than simply shifting parameter values. The model structure was changed accordingly or some extra dynamics were included to test the effect of these structures against the predicted output of the model.

The outcome of the model testing phase is discussed in the concluding chapter, i.e. Chapter 10. The discussion on the test results is combined with the evaluation and discussion on shortcomings in the models.

Before a discussion on the actual development of the conceptual model, the tools used to develop the dynamic model are discussed briefly.

## 4.5 System Dynamics Tools

This section describes the system dynamics tools employed in this thesis. The two sub-sections describe, introduce and explain the concepts of causal loop diagrams as well as stock and flow diagrams.

### 4.5.1 Causal loop diagrams

Causal Loop Diagrams (CLD) is an important tool to represent a system's feedback structure. CLDs are especially beneficial for (Sterman, 2000, 139):

- quickly capturing hypotheses about causes of dynamics
- eliciting and capturing mental models of individuals or teams; and
- communicating important feedbacks believed to be responsible for the system's behaviour.

Causal diagrams consist of variables connected by arrows that denote causal influences among the variables. Important feedback loops are also identified in the diagram. The following figure explains the notation used in these diagrams.

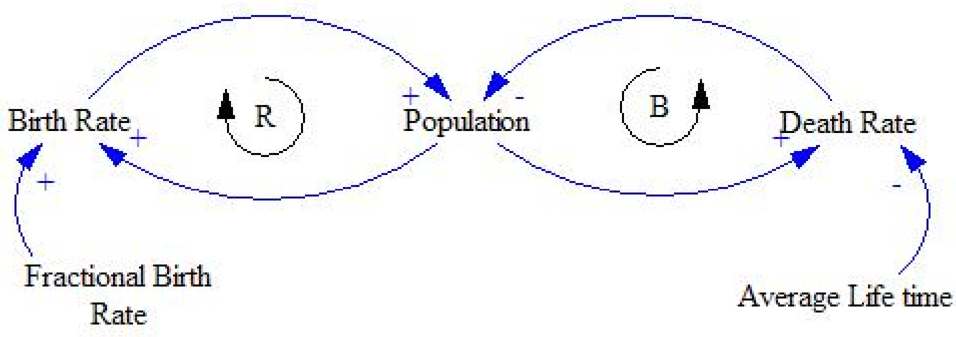



**Figure 4-6: Causal loop Diagram Notation Example**

Casual links are the lines with arrowheads that connect variables in a causal diagram, e.g. birth rate and population is connected with a causal link with polarity +. Link polarities are indicated at the arrowheads. Positive/reinforcing loops are indicated with an 'R' and negative/balancing loops are indicated with a 'B'. There are two polarities, namely a positive and a negative polarity.

A positive link, as shown between birth rate and population, indicates that where a change occurs in the controlling variable, the controlled variable will change in the same direction. To illustrate this point more clearly:

- should the controlling variable, *birth rate*, increase, the controlled variable, *population*, will increase to above the level it would have been; and
- should the controlling variable, *birth rate*, decrease, the controlled variable, *population*, will decrease to below the level it would have been. This is also known as a *positive or reinforcing feedback loop.*

A negative link indicates that a change in the effect will also result in a change in the opposite direction to the cause. To illustrate this point more clearly:

- should the controlling variable, *average life time*, increase, the controlled variable, *death rate*, will decrease to below the level it would have been; and
- should the controlling variable, *average life time*, decrease, the controlled variable, *death rate*, will increase to above the level it would have been.

Time delays can also be indicated in causal loop diagrams. The following figure depicts the causal relationship between road construction and the road's traffic capacity.

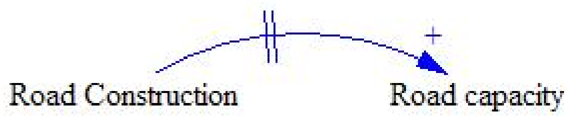



**Figure 4-7: Causal Indicator with a Delay Marking**

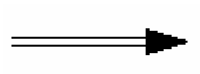
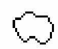
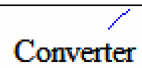
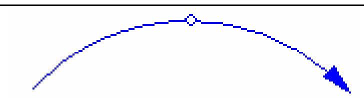
This section shortly described some concepts in the documentation of CLDs. In following sections, these diagrams will be used to convey important feedback loops and causal relationships between elements in a system.

CLDs do however suffer from a number of limitations, the most important of these its failure to capture what is actually happening in the system but only what would happen should something change. CLDs thus fail to capture the stock and flows structure of a system (Sterman, 2000). The following section describes stocks and flows in more detail.

### 4.5.2 Stocks and flows

Along with feedback, stocks and flows are the two central concepts of dynamic system theory.

**Table 4-2: Building Blocks of the Stock and Flow Diagrams**

| | |
|---|---|
| **Stocks** represent entities in the system where contents and levels can fluctuate during the period of simulation. Content of levels is cumulative of behaviour in previous time intervals. |  |
| **Flows** represent movements of entities in the system. Equations governing flow provides the rate of the flows. Flows can be physical or abstract |  |
| **Valves** control flows |  |
| **Sources and sinks** are indicated with clouds. A source represents the stock from which a flow originate outside the boundary of the model arises. Sinks represent sinks into which flows leaving the model drain. |  |
| **Converters** represent variables influencing behaviour of stocks and flows, e.g. the gravity constant will be defined by a converter. |  |
| **Connectors** represent linkages between various elements in the system |  |

The stock and flow diagram for the population causal loop depicted in Figure 4-6 will take on the following form:

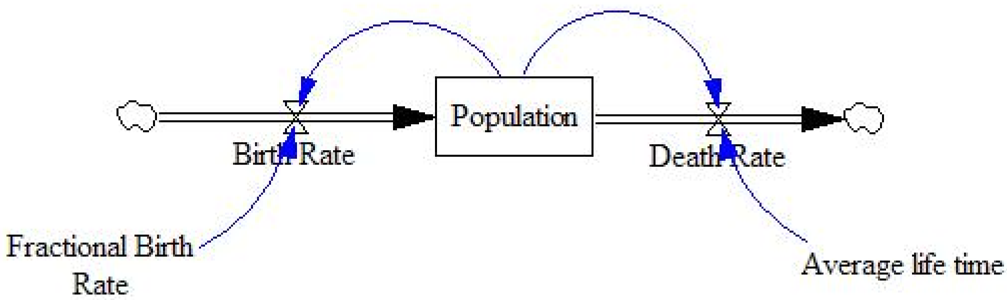



**Figure 4-8: Stock and Flow diagram of a Population Model**

Stocks make a very important contribution to dynamics (Sterman, 2000):

- characterises the state of the system and provides the basis for actions
- provides systems with inertia and memory. Stocks accumulate past events, as its content

can only change with an inflow or outflow
- forms the sources of delays. Differences between inputs and outputs accumulate in a stock of material in process; and
- decouples rates of flow and create disequilibrium dynamics. The differences between inflows and outflows are absorbed by stocks, allowing the inflow and outflow process to differ.

A major strength in the stock and flow representation is the clear distinction between physical flows through the stock and flow network and the information feedback loops that close the loops in the system. Stocks are reserved in the system because if stocks flow from one to the other, the first stock loses exactly as much as the other gains.

### 4.6 Mathematical Representations of Stocks and Flows

Sterman (2000) states that the stock and flow diagramming convention is based on the hydraulic metaphor, i.e. the flow of water in and out of reservoirs. The quantity of material in any stock is the accumulation of material into the stock minus the flow of material out of the stock. Stocks accumulate or integrate their flows. The net flow into the stock is therefore the rate of change of the stock.

$$Stock(t) = \int_{t_0}^{t} Inflow(s) - Outflow(s)ds + Stock(t_0) \qquad \textbf{4-1}$$

$Inflow(s)$ represents the value of the inflow at any time between the initial time $t_0$ and the current time $t$. $Outflow(s)$ represents the value of the outflow at any time $s$ between the initial time $t_0$ and the current time $t$. The net rate of change of any stock, i.e. its derivative, is the inflow less the outflow, which defines the following differential equation:

$$d(Stock)/dt = Inflow(t) - Outlfow(t) \qquad \textbf{4-2}$$

In general, the flows can be described as functions of the stocks as well as other state variables and parameters.

In this thesis, the INTEGRAL() function will be used when referring to the accumulation of a stock:

**Stock =** Integral **(Inflow-Outflow) + Stock value at** $t_0$ **4-3**

#### 4.6.1 Simulation software

The software package chosen for the development of the simulation model is Stella™ version 8.

Stella™ is a visual modelling tool that allows system modellers to conceptualise, document, simulate, analyse and optimise models of dynamic systems. Stella provides a simple and flexible way of building simulation models from causal loop or stock and flow diagrams. The following is a screen shot of a simple stock and flow diagram in Stella:

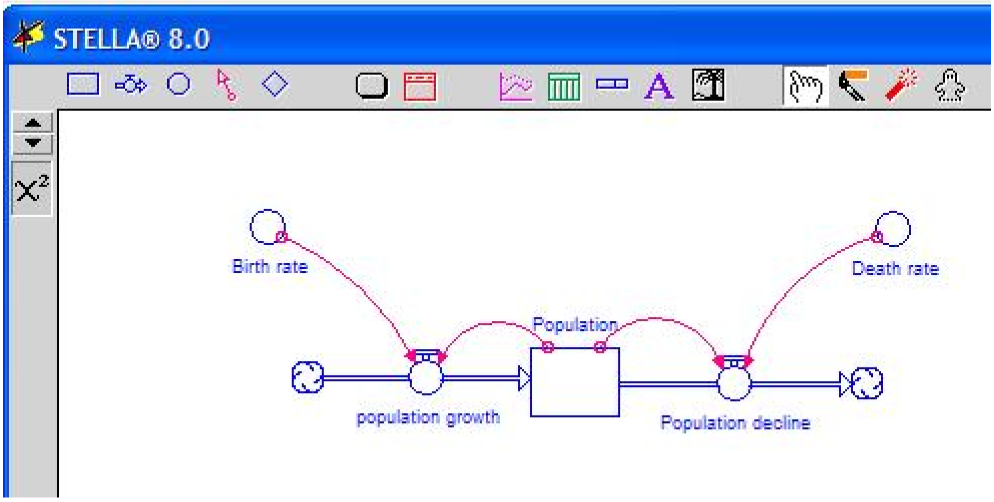



**Figure 4-9: Stock and Flow Diagram in Stella 8.**

The software package generates differential equations graphically as the analyst creates a model of a system graphically. The following is a screen shot of the system of differential equations developed by the software:

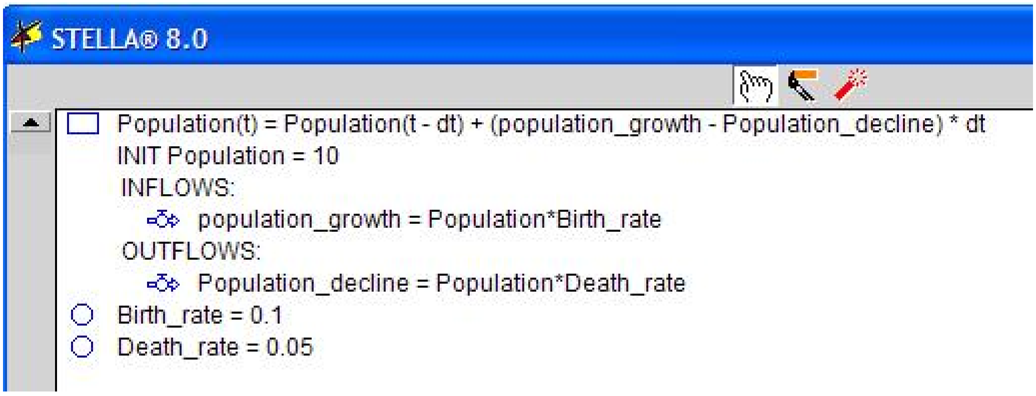



**Figure 4-10: System of Differential Equations Developed by the Software**

It is essential to test the model thoroughly to ensure that it captures the most important aspects of the system it represents. The following section discusses the model testing and validation strategy followed in this thesis.

## 4.7 Dynamic Hypothesis Testing and Validation Strategy

> *"Many modellers speak of model validation" or claim to have 'verified' a model. In fact validation and verification of models is impossible….no model can ever be verified or validated. Why? Because all models are wrong…all models, mental or formal are limited, simplified representations of the real world. They differ from reality in ways large and small, infinite in number.*
>
> *If validation is impossible and all models are wrong, why do we bother to build them? It is the modeler's responsibility to make sure that the best model is used. Instead of seeking a single test of validity model either pass or fail, good modelers seek multiple points of contact between the model and reality by drawing on many sources of data and a wide range of tests.*" (Sterman, 2000)

Sterman (2000:846) stresses the importance of testing the model. He also emphasises that the modeller refrain from focussing only on the recreation of historical data, but to also consider the underlying assumptions, robustness, and the sensitivity of results to assumptions. He presents a detailed description of the different tests that should be performed on the model.

The tables in each one of the following subsections include the questions asked to test the model developed in this research project. These tables are abstractions from Sterman (2000), which is a summation of work done by Forrester (1973), Forrester and Senge (1980) and Barlas (1989, 1990, and 1996).

### 4.7.1 Dimensional consistency test

The dimensional consistency test was among one of the very first tests executed on the models. Instead of specifying the units of measure after the model is developed, specification should take place as the model is developed. This test was conducted to ensure that all equations are dimensionally consistent without the inclusion of arbitrary scaling factors that have no real world meaning.

| Purpose of the Test | Tools and Procedures |
|---|---|
| Is each equation dimensionally consistent without the use of parameters with no real world meaning? | • Use dimensional analysis software.<br>• Inspect mode equations for suspect parameters. |

### 4.7.2 Boundary adequacy test

The boundary adequacy test assesses the appropriateness of the model boundary for the specific model purpose. The following table summarises the tools used to determine the adequacy of the model boundary:

| Purpose of the test | Tools and Procedures |
|---|---|
| • Are the important concepts for addressing the problem endogenous to the model?<br>• Does the model's behaviour change significantly when boundary assumptions are relaxed?<br>• Do the policy recommendations change when the model boundary is extended? | • Model boundary charts, subsystem diagrams, stock and flow maps as well as and direct inspection of model equations.<br>• Use interviews and workshops to solicit expert opinion, archival materials, review of literature and direct inspection/participation in system processes.<br>• Modify the model to include plausible additional structure. Make constants and exogenous variables endogenous before repeating sensitivity and policy analysis. |

### 4.7.3 Structure assessment test

The structure assessment test is performed to determine whether the model is consistent with the real system when keeping the purpose of the model in mind. This test aims to identify 'free lunches', inconsistencies and inappropriate assumptions. Violations of physical laws can be attributable to either inappropriate assumptions or the model's inability to capture the stock and flow structure of the real system adequately. 'Free lunches' can be described as activities that are assumed to occur, yet the occurrence is not backed by the important resources that it needs to occur in the real world.

| Purpose of the Test | Tools and Procedures |
|---|---|
| • Is the model structure consistent with the system's relevant descriptive knowledge?<br>• Is the level of aggregation | • Use policy structure diagrams, causal diagrams, stock flow diagrams and direct inspection of the model.<br>• Use interviews and workshops to solicit expert opinions, archival materials, direct inspection or participation in the |

| | |
|---|---|
| appropriate?<br><br>• Does the model conform to basic physical laws, such as conservation laws? | system processes.<br>• Conduct partial model test on the intended rationality of the decision rules.<br>• Develop disaggregated sub models and compare behaviour to aggregate formulations.<br>• Disaggregate suspect structures before repeating sensitivity and policy analysis. |

### 4.7.4 Parameter assessment test

Before estimating parameters, the author ensured each variable had a real world meaning. The next step was to devise a plan on how the parameters would be estimated. Basic choices included formal statistical estimation or judgemental estimations. In the end, a combination of these two options was followed.

Throughout the formulation of the stock and flows structure, numerous parameters were estimated from either literature or judgement. These estimations are discussed in more detail in Chapters 7 to 9.

The thesis follows a statistical estimation of the parameters included in the knowledge production functions, while linear regression techniques are applied to the parameter estimation. The estimated models were tested for co-linearity, autocorrelation and heteroscedasticity. Stationarity tests conducted on the models tested the spuriousness of the modelled relationships.

| Purpose of the Test | Tools and Procedures |
|---|---|
| • Are the parameter values consistent with relevant descriptive and numerical knowledge of the system?<br>• Do all parameters have real world counterparts? | • Use statistical methods to estimate parameters (wide range of methods available).<br>• Use partial model tests to calibrate subsystems.<br>• Use judgement methods based on interviews, expert opinion, focus groups, archival materials, direct experience, etc.<br>• Develop disaggregate sub models to estimate relationships for use in more aggregate models. |

### 4.7.5 Extreme conditions test

For the purposes of this research project, the model was tested for robustness in extreme conditions. To pass this test, the model must behave realistically no matter how extreme the inputs or policies imposed on it. The methods used to ensure the above included both direct inspection of the equations as well as simulation.

An example of such a test performed on the system was gauging the model's reaction if the amount of human resources performing R&D was reduced to zero. A realistic reaction to the above situation would be for the entire system's R&D production to drop to zero as well.

During the modelling study, the author took great care to ensure that any implausible behaviour caused by extreme conditions would be examined in detail to identify the precise source of the flaw.

| Purpose of the Test | Tools and Procedures |
|---|---|
| • Does each equation make sense, even when its inputs take on extreme values?<br>• Does the model respond plausible when subjected to extreme policies, | • Inspect each equation.<br>• Test response to extreme values of each input, alone and in combination.<br>• Subject the model to large shocks and extreme conditions. Implement tests that examine conformance to basic physical |

| | |
|---|---|
| shocks and parameters? | laws, e.g. no inventory, no shipments, no labour and no production. |

### 4.7.6 Integration error test

System dynamics models are formulated in continuous time and solved by numerical integration. The integration method (Euler's method) as well as the time step (0.125 year) was selected with utmost care to ensure accuracy for the purpose of the model.

Tests were executed to gauge model sensitivity regarding these two issues.

| Purpose of the Test | Tools and Procedures |
|---|---|
| Are the results sensitive to the choice of time step of numerical integration method? | Cut the time step in half and test for changes in behaviour. Use different integration methods and test for changes in behaviour. |

### 4.7.7 Behaviour reproduction test

Numerous tools are available to assess the model's ability to recreate and reproduce the system's behaviour. It is imperative to understand both the source and the size of the error. Plotting the simulated and actual output together is a powerful way of assessing the main trends that the model follows as well as pinpointing where it fails to follow the most important trends.

A statistical method is employed to calculate the coefficient of determination ($R^2$) to find an expression of the fraction of the variance explained by the model.

| Purpose of the Test | Tools and Procedures |
|---|---|
| • Does the model reproduce the behaviour of interest in the system both qualitative and quantitatively?<br>• Does it generate the symptoms of difficulty motivating the study?<br>• Does the model generate the various modes of behaviour observed in the real study?<br>• Do the frequencies and phase relationships among the variable match the data? | • Compute statistical measures of correspondence between model and data: descriptive statistics (R^2, MAE), time domain methods, e.g. autocorrelation functions, frequency domain methods, e.g. spectral analysis, etc,<br>• Compare model output and data qualitatively, including modes of behaviour, shape of variables, asymmetries, relative amplitudes and phasing, unusual events.<br>• Examine response of model to test inputs, shocks and noise. |

### 4.7.8 Behaviour anomaly test

The behaviour anomaly test examines the importance and strength of relationships within the model by scrutinising the alteration in output where a specific structure is left out or changed. This is also referred to as 'loop knock out analyses.

A loop knockout analysis was performed on the simulation model to determine the importance of a number of variables in the system.

| Purpose of the Test | Tools and Procedures |
|---|---|
| Does anomalous behaviour result when assumptions of the model are changed or deleted? | • Zero out key effect (loop knockout analysis).<br>• Replace equilibrium assumptions with disequilibrium structures. |

### 4.7.9 Family member test

This test questions the model's ability to generate output for real life systems belonging to the same class the system is meant to mimic.  The more different instances the model is able to represent, the more general the theory becomes. This test is particularly useful where the class that the model belongs to include a wide variety of behaviours.

The conceptual model of an R&D subsystem developed in this study was applied to three R&D performing sectors in the South African NSI. This application also tests the generality of the formulation of the conceptual R&D sector model developed in this thesis.

| Purpose of the Test | Tools and Procedures |
|---|---|
| Can the model generate the behaviour observed in other instances of the same system? | Calibrate the model to the widest possible range of related systems. |

### 4.7.10 Surprise behaviour test

Discrepancies between the model's output and the actual historical data indicate that the model is flawed. This flaw can lurk in either the mental or the formal model or both. Since the problem of reliable time series data is a well-known dilemma, the actual data was also examined as a possible source of the problem.

Surprise behaviour occurs when a model generates a previously unrecognised behaviour, one that actually occurs in the system. To ensure the test's effectiveness, the model behaviour was analysed closely.

| Purpose of the Test | Tools and Procedures |
|---|---|
| Does the model generate previously unobserved or unrecognised behaviour? | • Keep accurate, compete, and dated records of model simulations. Use the model to simulate likely future behaviour of the system.<br>• Resolve all discrepancies between model behaviour and your understanding of the real system.<br>• Document participant and client mental models before starting the modelling effort. |

### 4.7.11 Sensitivity analysis test

Since all models are simplifications of reality, the robustness of the model was tested through uncertainty in the assumptions. Sensitivity analysis questions whether the conclusions change in ways that are important to the purpose of the model where assumptions are varied over plausible ranges of uncertainty. The type of sensitivity of concern in any project depends on the purpose of the model. The three types of certainty tested for are described in the following table:

| Purpose of the test | Tools and Procedures |
|---|---|
| • *Numerical Sensitivity:* Do the numerical values change significantly?<br>• *Behaviour sensitivity:* Do the modes of behaviour generated by the model change significantly?<br>• *Policy sensitivity:* Do the policy implications change significantly when assumptions about parameters, boundary and aggregate are varied over the plausible range of uncertainty? | • Perform univariate and multivariate sensitivity analysis.<br>• Use analytic methods, i.e. linearisation, local and global stability analysis, etc.<br>• Conduct model boundary and aggregation tests.<br>• Use optimisation methods to find parameter combinations that generate implausible results or reverse policy outcomes. |

### 4.7.12 System improvement test

System improvement test questions whether the modelling process has succeeded in enhancing the system. To pass this test, policies aimed at an improvement of system performance were designed. Once implemented, the effect on the model was tested to see if it predicts an improvement in system performance.

In essence, it is extremely difficult to determine improvement in a system regarding changes. Rigorous follow up research is therefore imperative to determine the success of the policy recommendations.

| Purpose of the Test | Tools and Procedures |
|---|---|
| Did the modelling process help change the system for the better? | • Design instruments - advance to assess the impact of the modelling process on mental models, behaviour and outcomes.<br>• Design controlled experiments with treatment and control groups, random assignment, pre-invention and post-intervention assessment, etc. |

## 4.8 Chapter Summary

This research project is a model or theory building study. Models can be defined as a simplified representation of more complex forms, processes and functions of physical phenomena or ideas. Scientists use models and theories in an attempt to explain phenomena in the world. Models allow predictive claims under certain conditions (Mouton, 2001:176).

The human mind is well adapted to building models of objects in space as well as models associating words and ideas. The human mind is however inadequate to construct and interpret dynamic models that represent change in time in complex systems (Forrester, 1968). It can therefore become extremely complex to develop analytical mathematical models when the system understudy exhibits non-linear behaviour. For such systems, the simulation process of using step-by-step numerical solutions is available.

In this project, secondary textual data is used through deductive reasoning to arrive at the conceptual model structure, after which the model structure will be tested, changed and modified. Since the model is only a simplified representation of reality, a number of misfits might occur between model behaviour and reality. As the success of a modelling study lies in the usefulness of the model developed, the model's accuracy and detail level must be appropriate for the purpose of the model.

The system dynamics methodology was followed to develop a model of the dynamic behaviour of R&D in the NSI. Numerous tests were conducted to ensure that the model building research is rigorous and accurate.

The following chapter documents the development of the conceptual model of R&D in the South African system of innovation.

# 5 CONCEPTUAL MODEL

## 5.1 Purpose and Outline of the Chapter

Following Forrester's (1973, 4) reasoning, the formulation of a system model must start with identifying the smallest number of components within which the dynamic behaviour understudy will be generated.

This chapter documents the development of a conceptual system dynamics model of R&D in the NSI. The following section derives major elements and concepts from the literature and theory review performed in previous chapters.

## 5.2 R&D Performing Sectors in the Model

This study draws heavily on existing data sources. Examples of information sources include the Frascati R&D surveys, the Department of Education, science council and university year reports as well as the innovation survey performed by the University of Pretoria in 2001.

The Frascati manual is used as a reference for developing the model structure as this document aims to standardise the collection of national R&D information. Such standardisation facilitates comparisons between country data as well as time series data. South Africa is also fully committed to follow this approach. It is therefore simply a sensible option to both acknowledge and use the same breakdown structure used in the survey instrument.

The Frascati manual prescribes the following breakdown structure for the collection of R&D data (OECD, 2002c: 54-74):

- business enterprise
- government
- private non-profit
- higher education; and
- abroad

As the private non-profit sector plays only a very small role in the South African R&D system, it is not analysed further in this study.

The model attempts to include the performance of R&D activities for the higher education, public and business sectors in South Africa. This sector breakdown is also directly in line with the breakdown identified for the NSI by Galli and Teubal (1997) in Chapter 2.

The abroad sector is not analysed explicitly as an R&D performing sector. Its influence and exchanges of resources is however implied in the endogenous R&D performing sector models.

Chapter 2 stated that no system could exist completely isolated from its environment. This is also evident from Freeman's (1987) definition of the NSI: "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies".

This aspect is incorporated to include the flows of resources between R&D performing sectors within South Africa as well as external R&D systems.

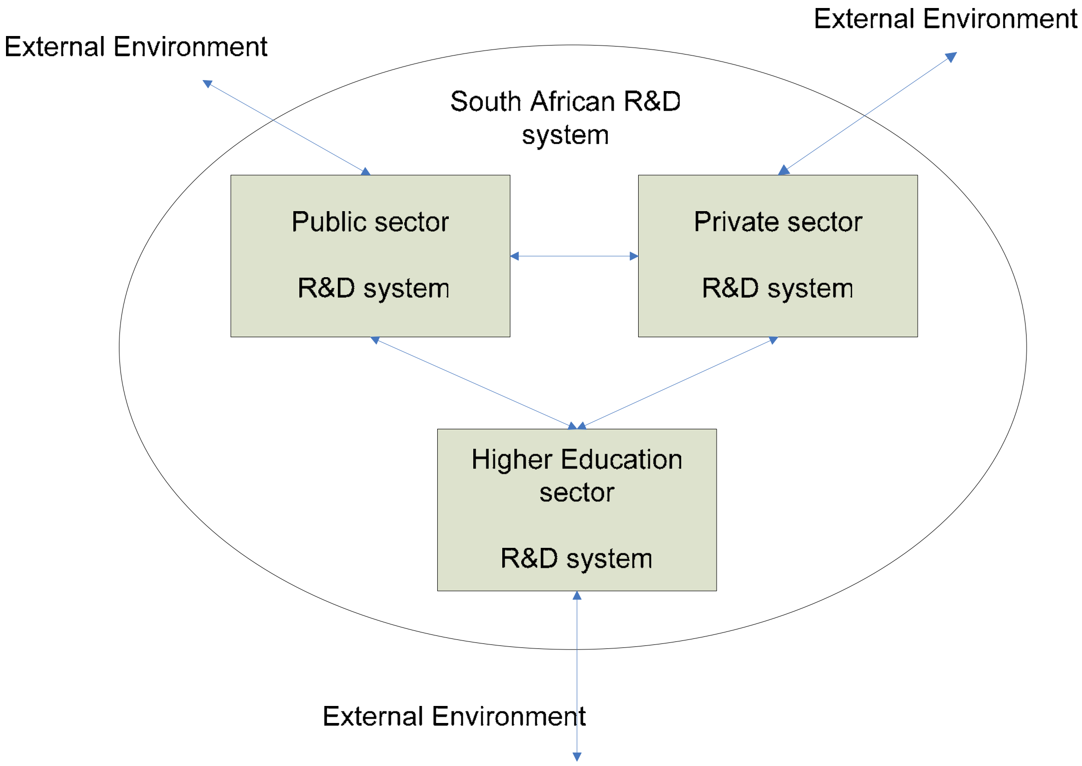



**Figure 5-1: Interaction and Flows between R&D Sector Models**

Figure 5-1 portrays a high-level view of interactions and flows between the major R&D performing sectors in the South African R&D system. Interactions and flows of resources occur across the system boundary to the exogenous environment. These flows and interactions also occur between R&D performing systems endogenous to the South African system, i.e. the higher education, business and public sectors.

This section emphasises that the South African R&D system does not exist in isolation, as flows exist between the South African and foreign R&D systems. Given the flow of knowledge and resource between them, the above is also true for the R&D performing sectors in the South African R&D system.

To both reach a clearer understanding of the important variables in the model and to glean a dynamic hypothesis, the basic structure of an R&D sector is derived from theory.

## 5.3 Generic Model for a Sectoral R&D System

This chapter focuses on developing a conceptual model of R&D in the South African system of innovation. The approach followed (see Figure 5-2) entails creating a generic model of an R&D performing sector. Numerous aspects and theoretical principles surrounding the performance of R&D are similar across different R&D sectors in a country. In an attempt to simplify the task of developing a model for the South African R&D system, the basic building block for the development is defined and derived first.

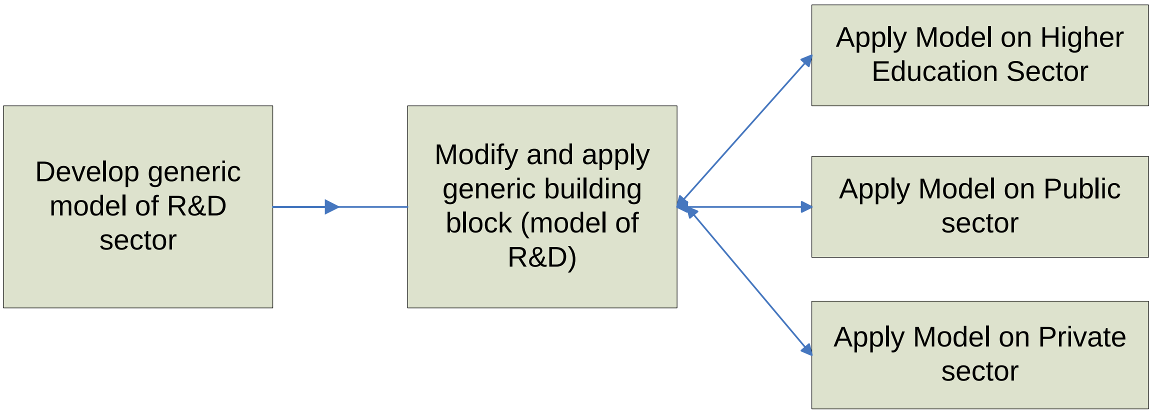



**Figure 5-2: The Application of the Generic Model on R&D Performing Sectors in SA.**

Although there are a number of similarities in the development of new knowledge on the one hand and the specific types of resources in R&D performing sectors on the other, they are unique in many ways. The conceptual model developed in this chapter is therefore applied and modified to suit the unique structure of the three R&D sectors that the model is applied to in Chapters 7 to 9.

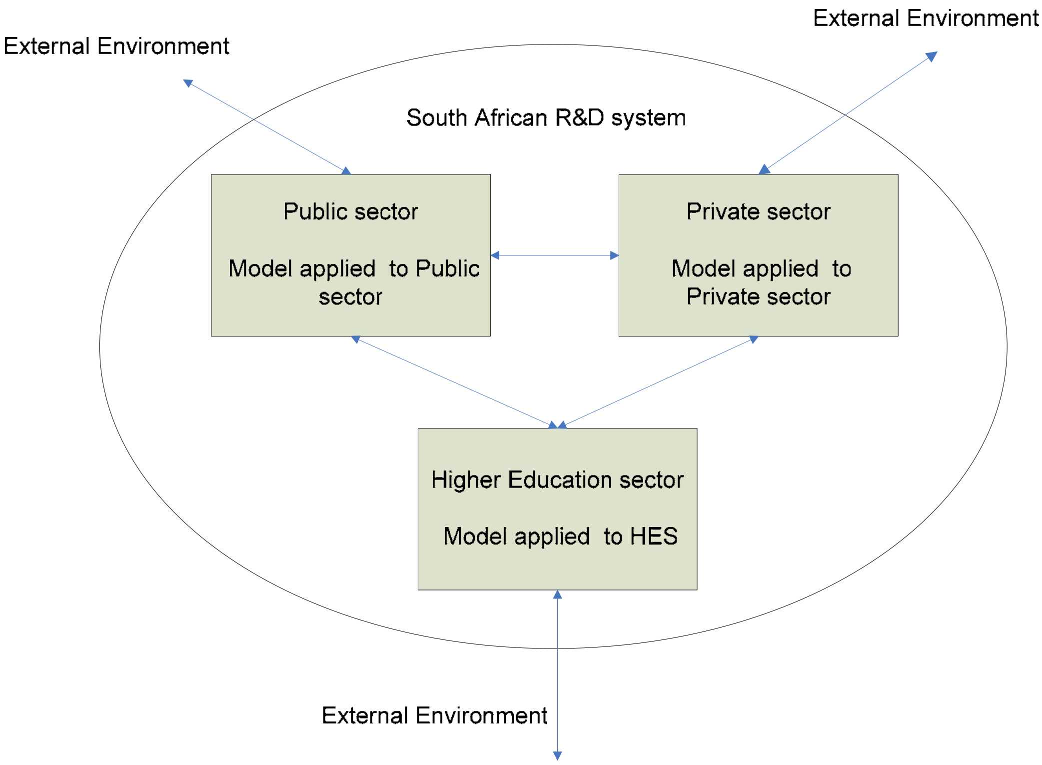



**Figure 5-3: High-level view of the Model Structure**

Figure 5-3 depicts a high-level view of the model structure indicating the three subsystem models. The reason for taking this approach is that it saves space and minimises rework in the formulation of dynamic hypotheses for the respective R&D performing sectors.

The next step is however to formulate and define the basic structure of an R&D performing sector model. The following section documents the derivation of the model structure from theory.

## 5.4 Theoretical Underpinning of the Dynamic Hypothesis

Freeman (1992:170) believes that although R&D is not the only source of technical change, it remains one of the main points of entry for new scientific development as well as the main focus for the development of new products and processes in most branches of industry.

It is crucial for any nation to develop an R&D capacity. The literature study concluded that an R&D investment aimed at developing an R&D capacity to create new knowledge as well as the ability to absorb new knowledge is important for a country's economical development ((Jones, 1995), Du Toit (2004)). Naturally, this also holds true for South Africa.

History plays an imperative role in the level of a system's development (Edquist, 1997). Within a complex system, events and developments are path dependent and take place over time. Small events are reinforced through positive feedback loops and become crucially important. The model developed in this section acknowledges the important role that the accumulation of *knowledge* and *skills* play in the development of an R&D system.

Romer (1990), Porter (1990), Lundvall (1992) and Johnson (1992), Niosi (2002), Nasierowski and Arcelus (1999) agree on the presence of human resources as an important input to the performance of R&D. Human resources engaged in R&D activities over a period of time, resulting in both the human resources building up and encapsulating tacit knowledge, know-how and skills. All the above are developed through experience. Non-codifiable knowledge or tacit knowledge encompasses the following:

- 'learning by doing' (Arrow, 1962)
- 'learning by using' (Rosenberg); and
- 'learning by interacting' (Lundvall, 1992b).

Lundval and Johnson's (1992) theory of interactive learning provides for the deterioration of knowledge, as it falls out of use or is replaced by new knowledge. Since R&D is performed in the system, the knowledge created can be expected to remain current and relevant for only a period of time after which it becomes obsolete.

The above section therefore concludes that human resources play a crucial part in the development of new knowledge. The development of new knowledge also results in human resources gaining insight and skills, referred to as tacit knowledge. The following sections deal with the dynamic human resources processes engaged in learning and the development of new knowledge.

### 5.4.1 The internal generation of new knowledge

The definition of R&D as documented in the Frascati manual states that R&D comprises the creation of knowledge, including knowledge of man, culture and society through the use of the stock of knowledge to devise new solutions (OECD, 2002c: 30). This definition highlights the central role that knowledge plays in generating new knowledge. Romer (1990), Lundvall (1992) and Rosenberg (2000) also support this view in their work.

The literature also acknowledges the role of capital resources (Christensen, 1992: 147) and capital assets as an important input to the R&D process ((OECD , 2002), (Porter, 1990). In the formulation of the model, capital assets stock is modelled as an aggregate stock of previous investment in equipment, land and buildings used by human resources to perform R&D.

The following figure captures this dynamic hypothesis:

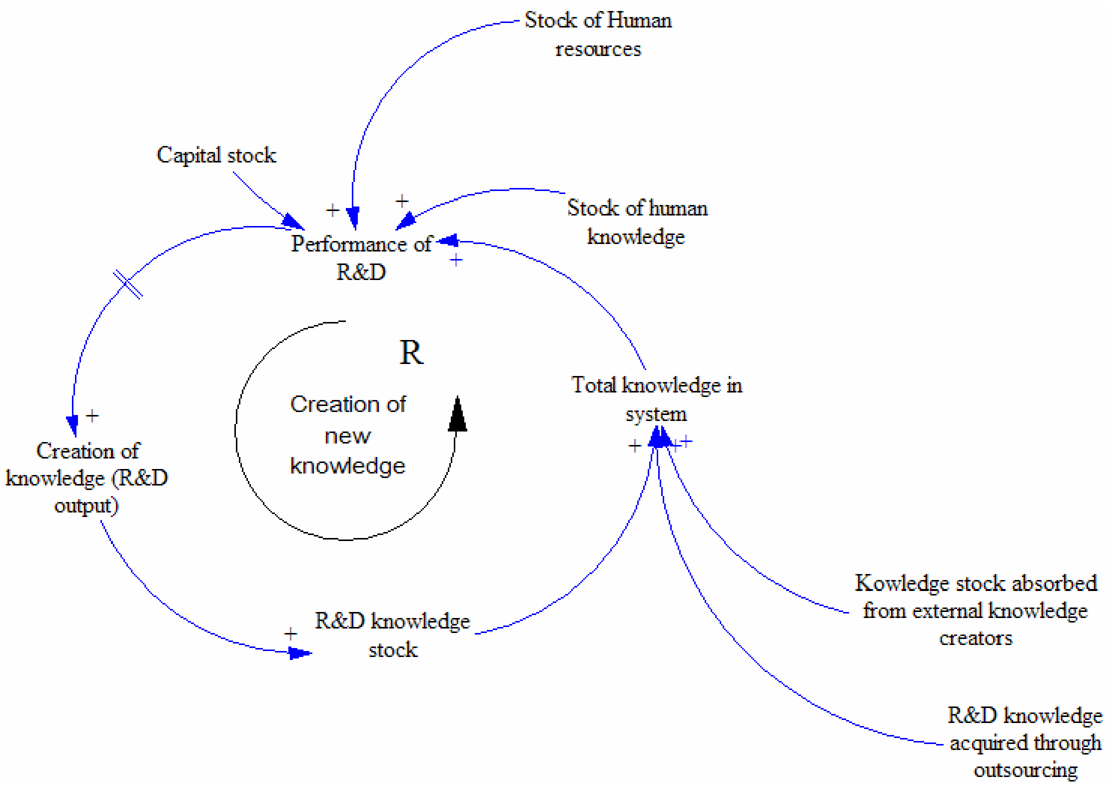



**Figure 5-4: The creation of knowledge by utilising existing knowledge**

The dynamic hypothesis aims to capture the process of R&D performance. The diagram captures a reinforcing loop. Human resources in an R&D system draw on capital stock, i.e. buildings, land and equipment, knowledge within the system as well as their own expertise and experience to perform R&D activities. Human resources also gain experience by performing R&D activities, resulting in a higher level of experience and expertise. Performing R&D activities result in new knowledge being created and ultimately in more knowledge being added to the 'R&D knowledge stock'.

Apart from the R&D knowledge stock and tacit knowledge of researchers, an additional knowledge stock can be identified. This is the absorbed knowledge stock. The following section describes the accumulation of this knowledge stock in more detail.

### 5.4.2 The absorption and acquisition of external knowledge

Werker and Fritsch (1999) provide a detailed explanation of the factors that influence the generation of knowledge. They believe that an organisation's performance with regards to the generation of knowledge depends on its ability to combine internal knowledge and external knowledge in a new way. This thus proves that the performance of R&D is also dependent on the acquisition and absorption of knowledge from external sources. It is also a direct implication that the organisation must at least possess the ability to identify, absorb and apply new knowledge for its own means, a process commonly referred to as the 'absorptive capacity' (Cohen and Levinthal, 1990).

Fritsch and Werker (1999) state that besides the ability to absorb information, the amount of knowledge actually transferred into the organisation is also dependent on the quantity, quality and the kind of knowledge available in the external environment.

The following figure represents a dynamic hypothesis as derived from the theory:

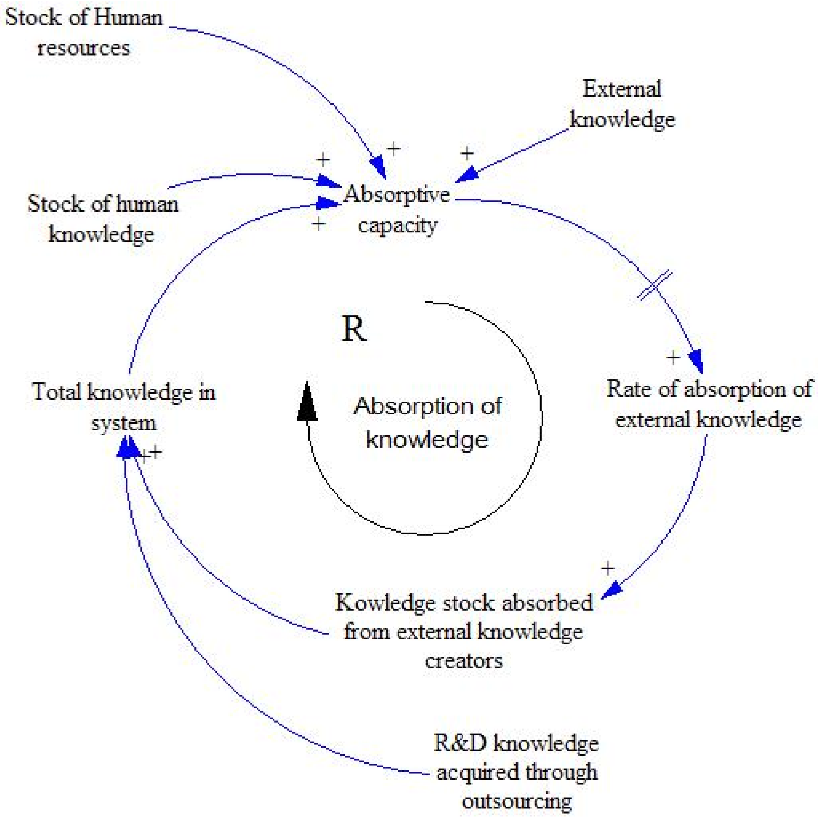



**Figure 5-5: Absorption of Knowledge through Knowledge**

The dynamic hypothesis displayed in Figure 5-5, represents a reinforcing loop for building system knowledge through the absorption of external knowledge. The loop displays dynamics involved in the absorption of knowledge from the external environment. This can only be achieved if the system has a level of absorptive capacity. The dynamic hypothesis assumes that the system's absorptive capacity depends on the presence of human resources, tacit knowledge and experience as well as previously generated and accumulated knowledge in the system. The absorptive capacity is also influenced by the external knowledge stock's characteristics. The system draws on its absorptive capacity to accumulate knowledge from the external environment.

As the successful performance of R&D depends on the successful integration of external and internal knowledge stocks, the following section deals with integrating the two reinforcing feedback loops that have been derived.

### 5.4.3 The integration of knowledge stocks

This section develops a dynamic hypothesis for the development of new knowledge. Figure 5-6 displays a dynamic hypothesis that incorporates the reinforcing loops derived from previous sections.

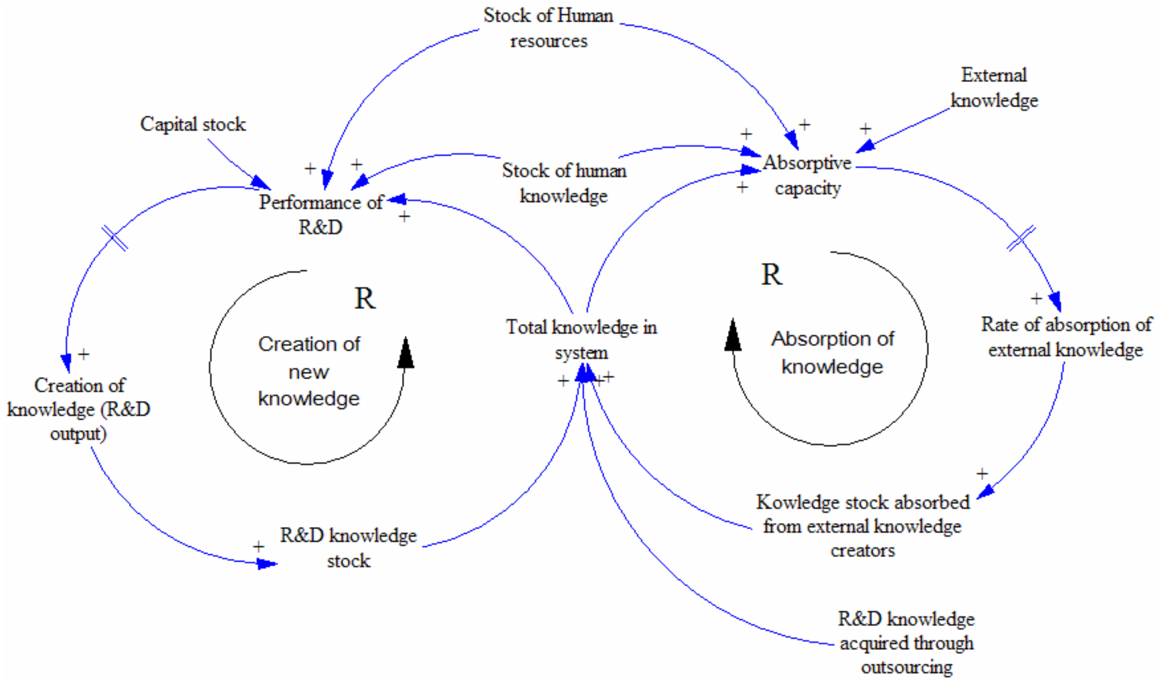



**Figure 5-6: Casual loop diagram of an R&D system**

Figure 5-6 depicts a CLD for integrated feedback loops of the creation of new knowledge and the absorption of knowledge. The creation of knowledge and the absorption of knowledge depend on the system's previous investment in human resources, the corresponding human knowledge stock as well as the current knowledge stock, i.e. the R&D knowledge stock and integrated external knowledge stock.

The CLD clearly depicts the relationships between variables and the system's feedback structure. CLDs however do not provide a way of communicating the model's physical structure. It also fails to capture the accumulation of goods as a result of flows in the system. The CLD developed up to this point is consequently expanded into a stock and flow diagram. The following section builds on the causal loop structure derived from theory.

## 5.5 Stock and Flow Diagram

Following the work of Romer (1990), Lundvall (1992) and Rosenberg (2000), the model acknowledges the central role of knowledge and the availability of human resources ((Romer, 1990), (Porter, 1990), (Lundvall and Johnson, 1992), (Niosi, 2002), (Nasierowski and Arcelus, 1999)) as inputs to system performance.

As indicated in the development of the causal loop structure, two main feedback loops can be identified within a sectoral R&D system, namely:

- an internal knowledge creation loop, i.e. an R&D performing loop; and
- absorption of external knowledge loop.

The formulation of the stock and flow diagram is based on the formulation of rate (flow) equations. Before the model is discussed in more detail, the formulation of the rate equations is explained. These rate equations involve the formulation of mathematical equations to estimate the influence that changes in stocks in the system might have on each other. To estimate the effect that a change in a stock ($X_i$) could have on a variable (Y), the following formulation is used:

$$\text{Change in Y because of } X_i = f(X_i / X_i^*) \quad \textbf{5-1}$$

The variable Y can either be a rate or an auxiliary that feeds into a rate. The non-linear functions are normalised by the normal or reference value of the inputs ($X^*_i$). The normalisation ensures that when the inputs $X_i$ equal their reference levels, the output Y equals its reference level. Normalising means the input and output of the effect of $X_i$ on Y are both dimensionless, allowing separation of normal values from the effects of deviation from normal.

*Reference levels throughout the model formulation are chosen to be the values for the initial levels of the stocks in the model.*

Throughout the model, the change in variable Y because of $X_i$ is modelled to take a power function form of the normalised inputs:

$$\text{Change in Y because of } X_1 = \left(\frac{X_i}{X_i^*}\right)^{a_i} \quad \textbf{5-2}$$

(Where $X^*_{i\,i}$ is the reference value for stock $X_i$)

The first aspect of the stock and flow diagram under scrutiny is the human resources stock and their associated tacit knowledge. The following section explains this stock and flow diagram subsection in more detail.

### 5.5.1 Human resources

As described in the section relating to the CLD, human resource stock in an R&D performing sector contributes to the creation and development of new technologies. It is also within the human resources that the majority of the tacit knowledge is stored. The dynamics involved in the headcount of research personnel in the system uses an ageing chain dynamic. This is an extremely common formulation and has been used by numerous modellers to model ageing properties in systems[1]. An ageing chain includes a number of stocks, which can also be called cohorts.

Figure 5-7 is a graphical representation of the ageing chain dynamics employed in the model. Each cohort has an inflow $R_{\inf low}(i)$ and an outflow $R_{outflow}(i)$. Research staff moves from cohort $i$ to cohort $i+1$ though the transition rate $R_{transition}(i,i+1)$.

[1] See Forrester (1969), Sterman (2000)

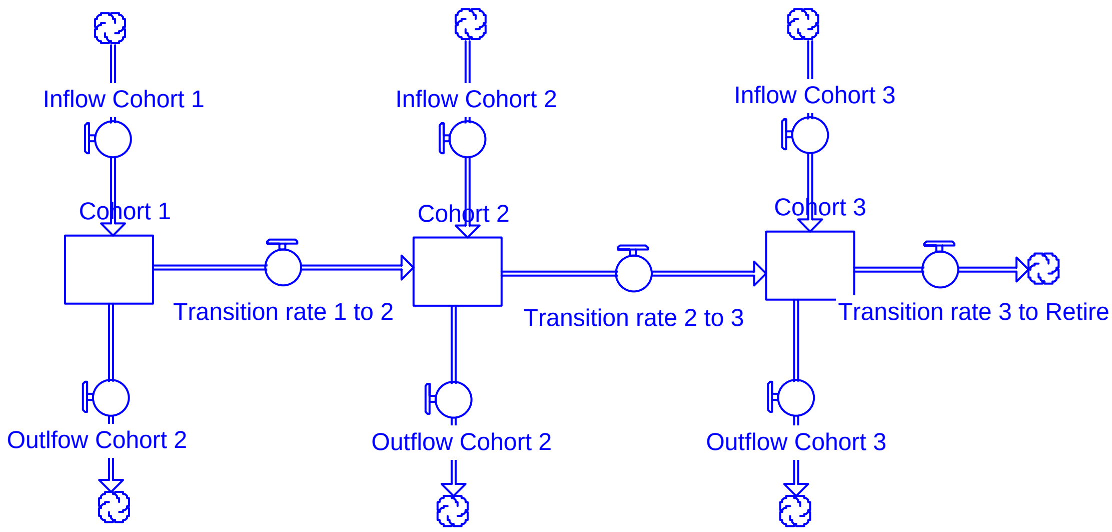



**Figure 5-7: Ageing chain of Human Resources in the HES**

The transition rate $R_{transition}(i,i+1)$ is modelled as a delay that takes the form of a first order process[2], $R_{transition}(i,i+1) = S_{HR}(i)/AT$ ,where AT denotes the average time residence before a person matures from the cohort to flow to the next.

Three stocks (cohorts) are used to capture flows of researchers of the following age groups:

- cohort 1 ($S_{HR}(1)$): young researchers aged 25-39 ($AT_1$ = 15)
- cohort 2 ($S_{HR}(2)$): experienced researchers aged 40-49 ($AT_2$ = 10); and
- cohort 3 ($S_{HR}(3)$): mature researchers aged 50 + ($AT_3$ = 15)[3]

The following expression can thus be formulated for the cohorts:

$$S_{HR}(i) = \text{integral}\,(R_{\inf low}(i) - R_{outflow}(i) - R_{transition}(i,i+1), S_{HR}(i)_{t_0}) \qquad \textbf{5-3}$$

Where $S_{HR}(i)_{t_0}$ is the initial value of $S_{HR}(i)$.

The inflow ($R_{\inf low}(i)$) of new human resources becomes a necessity as older staff retires or as human resources leave the system for whatever reason ($R_{outflow}(i)$). The system employs the dynamic of a goal-seeking loop, thus comparing the current headcount in the system with the target headcount in the system.

[2] A first-order outflow from a stock implies that the stock contents are mixed perfectly. More specifically, the probability that a particular item will exit is independent on the time it entered the stock. The number of cohorts can be increased until it represents a reasonable approximation of the real system

[3] An average Retirement rate of 65 years is assumed.

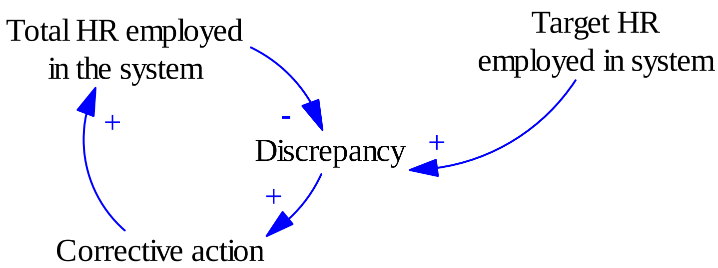



**Figure 5-8 Goal Seeking Behaviour Employed in the Model**

Should there be a discrepancy between the human resources employed in the system, the system will automatically take corrective action by either allowing a flow of academics into the system (hiring - $R_{\inf\ low}(i)$) or by an outflow (retrenching or firing the people - $R_{outflow}(i)$).

Discrepancy = Target Headcount – Total Headcount

The following two sections describe the detail around how $R_{outflow}(i)$ and $R_{\inf\ low}(i)$ are computed.

### 5.5.1.1 Inflow of human resources into the system

Where discrepancy > 0, the system employs less people than the target amount and should thus appoint new people. The decision as to which stocks the people should be assigned is made through the inflow percentage distribution parameters $A_{\inf\ low}(i)$ in the model.

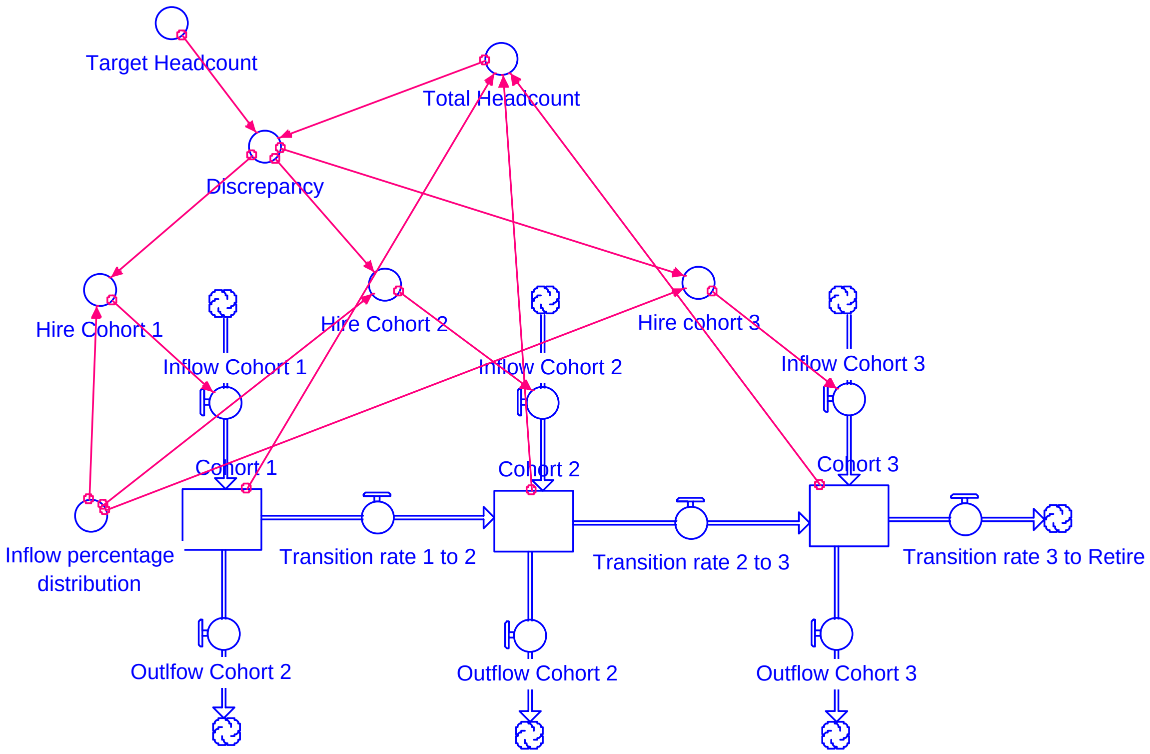



**Figure 5-9 Ageing Chain Dynamic with Employment Dynamic Included**

$$\text{Where } Discrepancy > 0,\ R_{\inf\ low}(i) = Discrepancy * (A_{\inf\ low}(i)) \text{ else } 0 \quad \textbf{5-4}$$

Where $A_{\inf\ low}(i)$ is the percentage distribution through which new appointments are made.

Where $\sum_{i=1}^{3} A_{\inf\ low}(i) = 1$ (These values are estimated in the model)

#### 5.5.1.2 Outflow of human resources in the system

Where *Discrepancy* < 0, the system employs more people than the target amount and should thus allow human resources to flow from the stocks to correct for the discrepancy.

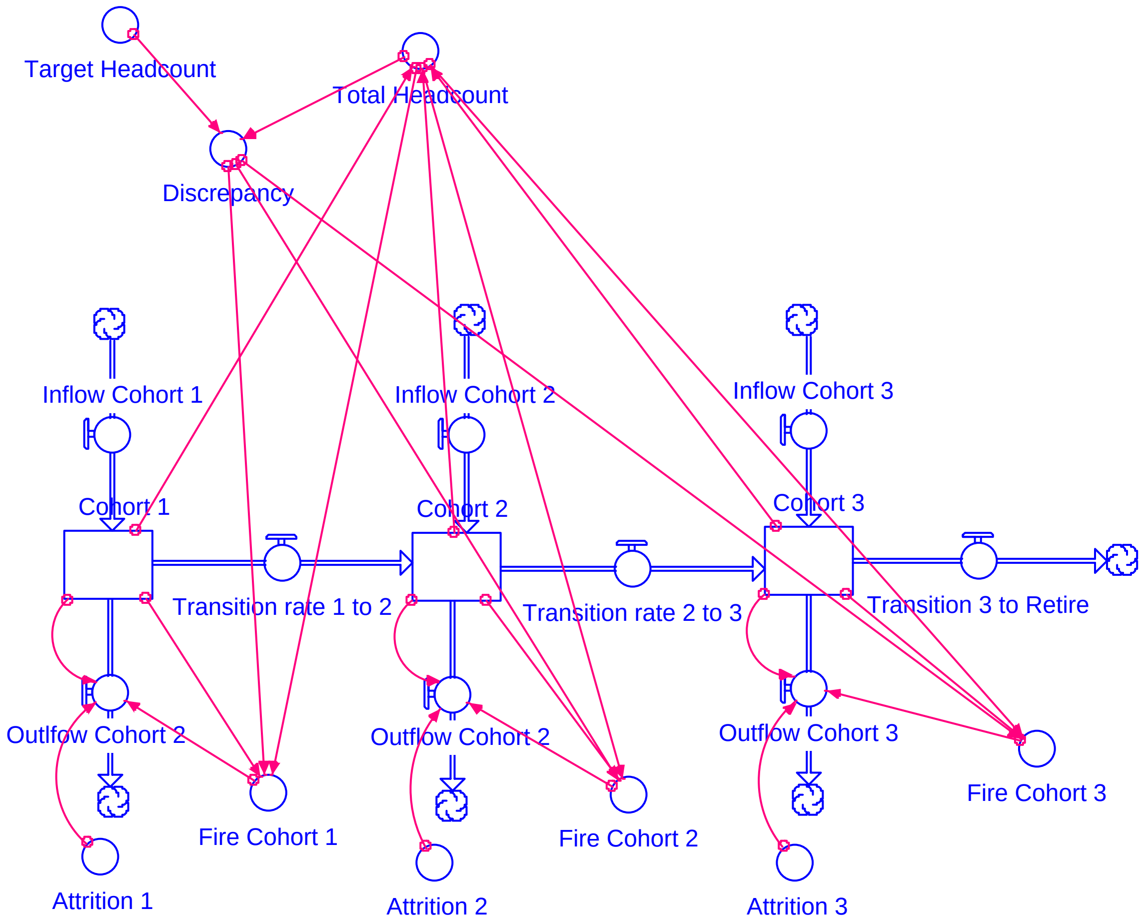



**Figure 5-10 Ageing Chain Dynamic with Outflow Dynamic Included**

It is safe to assume that the human resources will flow in the same distribution as represented in the cohorts.

If *Discrepancy* < 0 then

Fire Cohort (i) = ABS (Discrepancy* $S_{HR}(i)$/Total Headcount) **5-5**

The natural attrition of human resources in the system is also included in the dynamic model. $Attrition(i)$ is included as a percentage of the total stock of people in each of the cohorts $(Cohort(i))$.

$R_{outflow}(i)$ = ABS ($Discrepancy$ * $S_{HR}(i)$/Total Headcount)+ $Attrition(i) * S_{HR}(i)$

**5-6**

It is essential that $Attrition(i)$ has to be estimated for the model.

### 5.5.2 The fulltime equivalent researchers in the system

The number of fulltime equivalent researchers employed in the system is computed from the actual headcount of people employed in the system in terms of the percentage time headcount personnel actually spent on R&D.

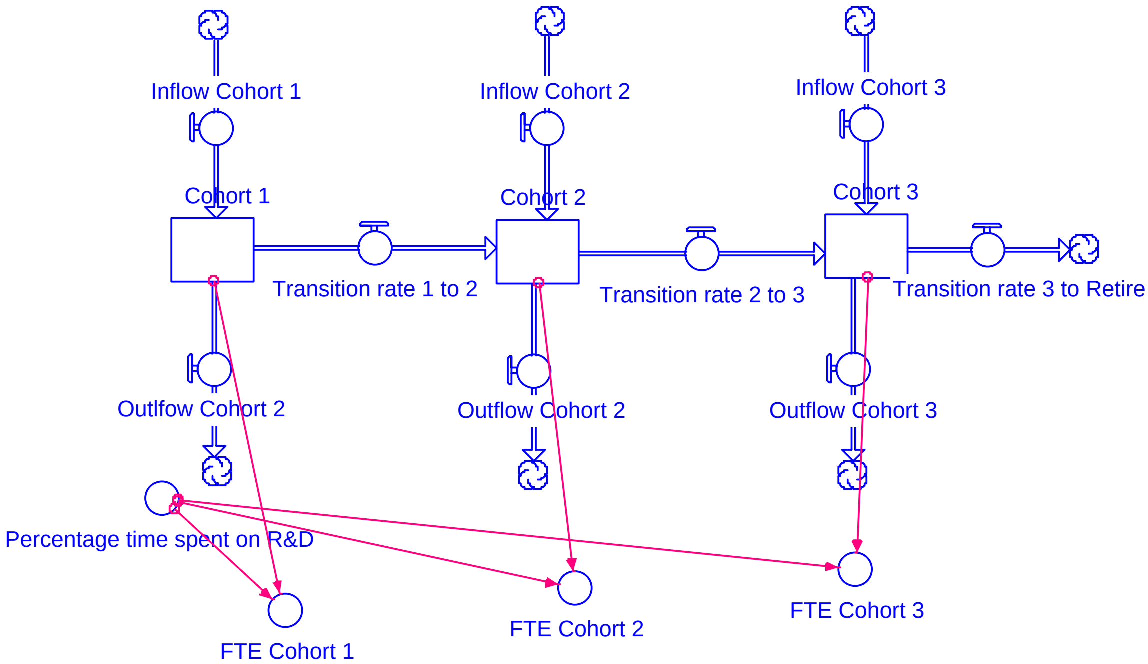



**Figure 5-11 Dynamic for the Computation of the FTE Researchers in the System**

In mathematical terms, the above can be expressed as follows:

$$FTE(i) = S_{HR}(i) \times \%TimeSpentonR\,\&\,D \qquad \textbf{5-7}$$

The value of $\%TimeSpentonR\,\&\,D$ has to be estimated for the sector on which the model is applied.

The following section takes a closer look at the development of the model in terms of the capacity developed in humans as they perform research.

### 5.5.3 Experience stocks

R&D is also introduced as a form of organisational learning. Cohen and Levinthal (1990) argue that R&D not only generates new information, but also enhances the ability to assimilate and exploit existing information. The long-term investment in developing R&D capacity is substantial and far from a trivial issue. The cost of learning is borne from the development of a stock of knowledge, which constitutes absorptive capacity.

Sterman (2000) employs learning curves in system dynamic models. Learning curves or experience curves have been documented in a wide range of industries. These curves arise as workers and firms learn from experience. As experience grows, workers find ways to work faster and reduce errors. Typically, the unit costs of production is bound to fall by a fixed percentage every time that cumulative production experience doubles. Learning by doing, know-how and are embedded in the organisation's capital stock, worker knowledge and routines. Although this knowledge stock is slow to develop, it also takes time to decay, provided that the human resources remain in the system.

It is therefore a safe assumption that a person should become more efficient and effective as his/her R&D experience level increases. This can be ascribed to the experienced person embodying a higher concentration tacit knowledge and more co-operation and relationships with other researchers than the average graduate who has just completed his/her studies. Following this reasoning, an assumption is made that as the average level of experience in the system increases, the tacit knowledge, know-how, general capability and co-operation of the researchers in the system is also bound to rise.

The following stock and flow structure is developed in an attempt to capture these flows and accumulation of human resources and experience:

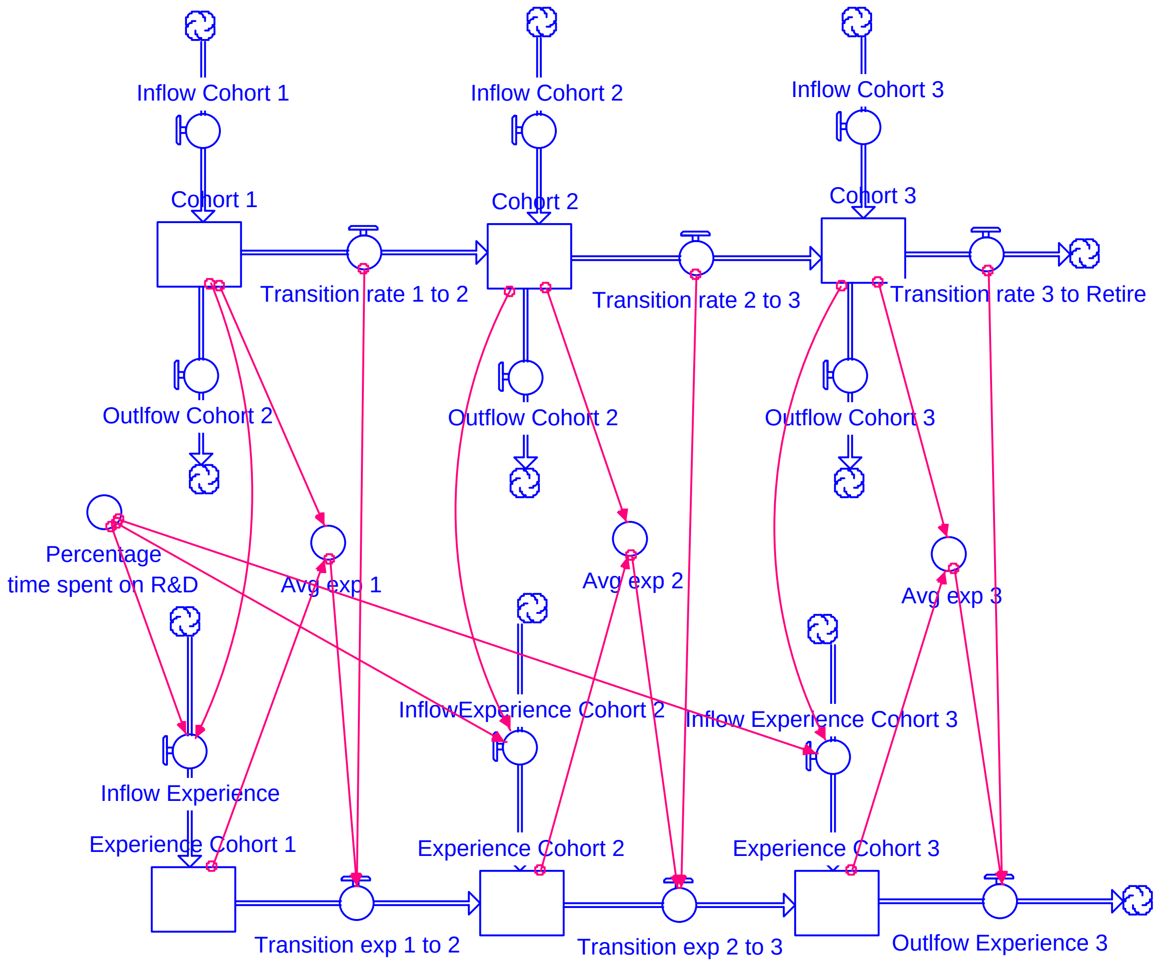



**Figure 5-12: The Stock and Flow Diagram of Human Resources and Experience.**

The stock of human knowledge is quantified in terms of years of experience. This is based on the argument derived from theory in a previous section that researchers with more experience possess more tacit knowledge and skills.

The stocks of skills in the system ($S_{skills}(i)$) thus accumulate at a parallel rate to academic and research personnel gaining more R&D experience. These stocks therefore accumulate with the fulltime equivalent researchers working in the system ($FTE\ (i)$). As academic and research staff matures and moves from one cohort to the next ($R_{iransition}(i, i+1)$), the relevant experience is also transferred ($A_{AvgExperience}(i)$).

Another mechanism not depicted in Figure 5-12 through which more skills can be gained is the rate at which the system employs new personnel ($R_{\inf low}(i)$) with an average level of experience that these new appointees already possess as researcher ($A_{New-\exp erience}(i)$). As researchers leave the system ($R_{outflow}(i)$), experience and tacit knowledge will also be lost to the R&D performing sector. Another factor that adds to the stock of skills depreciating is people 'forgetting' or knowledge falling in disuse.

To ensure that the system continues to produce research output, a human resource stock is imperative, especially one that is continually replenished with new graduates. The current experience stock, measured in total years experience in R&D by al human resources in the system, is therefore identified as an important input to the performance of R&D in the system.

This section described the human resources subsystem of the model. The following section focuses on the role of knowledge stocks and human resources in the performance of the system.

### 5.5.4 Effect of investment on R&D and assimilation of knowledge

Recalling the two major feedback loops, i.e. the creation of knowledge and the absorption of knowledge,) identified in the development of the CLDs, two rate equations are computed from the stocks in the system:

- rate of knowledge creation; and
- rate of knowledge absorption.

For the purpose of this model, a performance index for each of these rates is formulated.

Since the human resources and knowledge stocks contribute to the overall effectiveness of the generation of new knowledge and the absorption of knowledge in varying ways, two different parameters are defined for the system performance. The system performance parameter for the development of new knowledge is defined as $A_{Performanc\ e}(R\ \&\ D)$, while the system performance parameter for the assimilation of new knowledge is defined as $A_{Performanc\ e}(ABS)$.

***Change in system performance because of human resources***

An important factor that contribute to the R&D system performance ($A_{Performanc\ e}$) is the availability of human resources. The change in the system performance as a result of changes in the human resources stock ($HR$) can thus be expressed as follows:

$$\text{Change in } A_{Performanc\ e}(R\ \&\ D) \text{ because of } HR = \left(\frac{HR}{HR^*}\right)^{a_5} \qquad \textbf{5-8}$$

and

Change in $A_{Performance}(ABS)$ because of $HR = (\frac{HR}{HR^*})^{\beta_5}$ **5-9**

Note: $HR^*$ refers to the reference value of the Human Resources (HR) stock

***Change in system performance because of knowledge***

Knowledge however has been identified as one of the influencing factors of system performance. The following stocks are included in the formulation of the production function of the absorption and the creation of knowledge:

- R&D knowledge stock ($S_{RD}$): stock of R&D output generated in the system
- absorbed knowledge stock ($S_{Absorbed}$): knowledge external to the R&D performing sector that has been absorbed by performing R&D activities; and
- human resources knowledge stock ($S_{skills}$): tacit knowledge and research skills inherent to the human resources working in the system.

The additive formulation for the influence that knowledge stock might have on the system performance ($A_{Performance}$) is thus formulated as follows:

***Change in*** $A_{Performance}(R\&D)$ ***because of knowledge*** $= (\frac{S_{HR}}{S^*_{HR}})^{a_1} * (\frac{S_{Absorbed}}{S^*_{Absorbed}})^{a_3} * (\frac{S_{RD}}{S^*_{RD}})^{a_4}$ **5-10**

and

***Change in*** $A_{Performance}(ABS)$ ***because of knowledge*** $= (\frac{S_{HR}}{S^*_{HR}})^{\beta_1} * (\frac{S_{Absorbed}}{S^*_{Absorbed}})^{\beta_3} * (\frac{S_{RD}}{S^*_{RD}})^{\beta_4}$

**5-11**

*Change in system performance*

From both the changes in system performance because of the knowledge in the system as well as the human resources present, a multiplicative formulation was chosen. The multiplicative nature of the formulation of the model indicates that human resources and knowledge must exist together in the model for the system to be able to perform. The fractional change in the system performance can thus be formulated as the following expressions:

**Change in** $A_{Perf}(R\&D) = (\frac{S_{HR}}{S^*_{HR}})^{a_1} * (\frac{S_{Absorbed}}{S^*_{Absorbed}})^{a_3} * (\frac{S_{RD}}{S^*_{RD}})^{a_4} * (\frac{S_{Skills}}{S^*_{Skills}})^{a_5}$ **5-12**

**Change in** $A_{Perf}(ABS) = (\frac{S_{HR}}{S^*_{HR}})^{\beta_1} * (\frac{S_{Absorbed}}{S^*_{Absorbed}})^{\beta_3} * (\frac{S_{RD}}{S^*_{RD}})^{\beta_4} * (\frac{S_{Skills}}{S^*_{Skills}})^{\beta_5}$ **5-13**

Now that an expression of the fractional change in system performance resulting from changes in the elements of an R&D system has been formulated, the feedback loops feeding from and into the system performance parameters can be characterised. Both the CLD as well as the outline of the stock and flow diagram indicate that the model consists of two reinforcing feedback loops.

- absorption of external knowledge; and
- creation of knowledge.

The following sections describe these feedback loops in terms of their stock and flow structures in more detail.

### 5.5.5 Loop 1: absorption of external knowledge

The following figure depicts the stock and flow diagram developed for the knowledge absorption and acquisition subsystem.

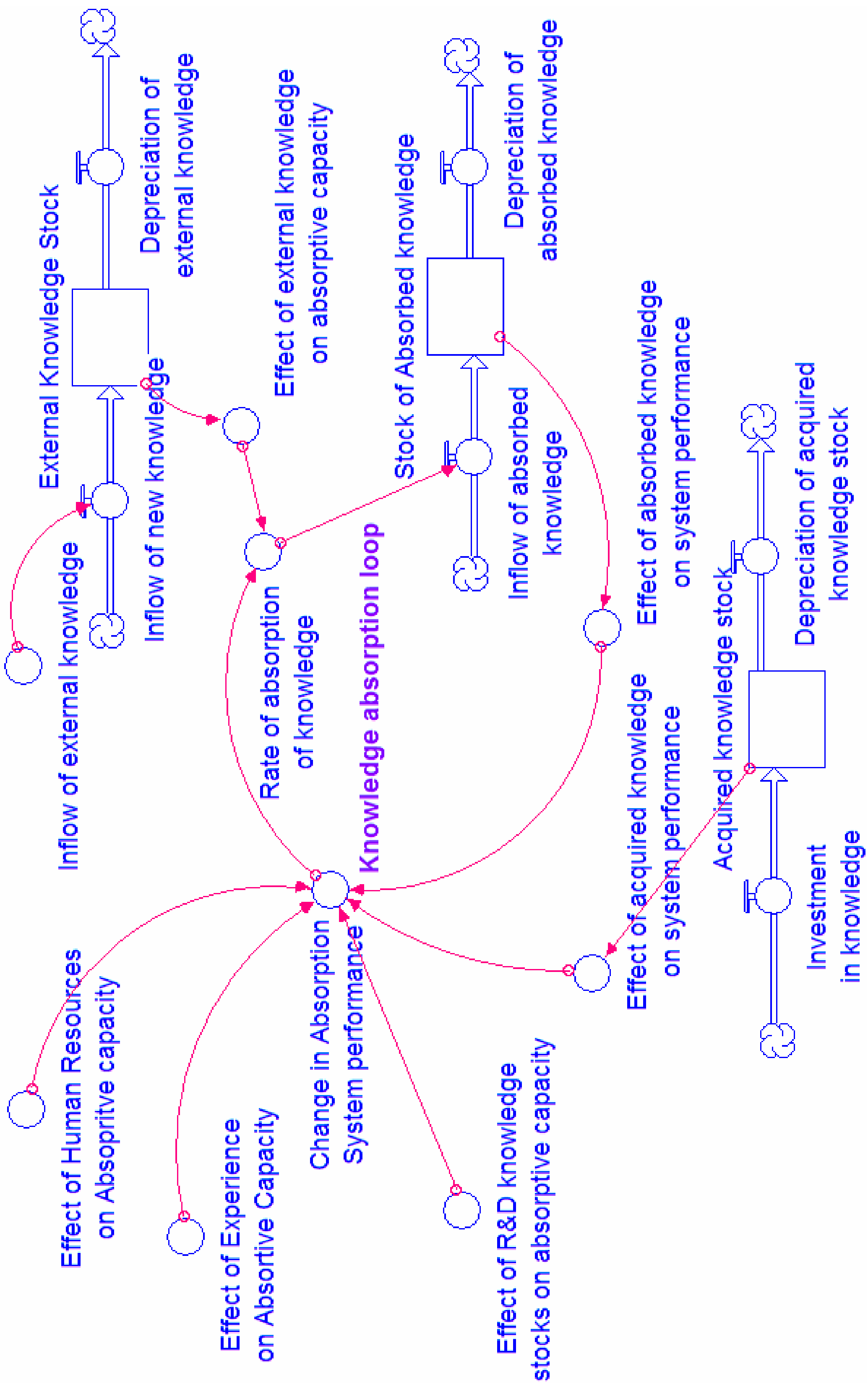



**Figure 5-13: The Absorption of External Knowledge**

In this stock and flow diagram, the rate at which knowledge is created in the external environment ($R_{External}$) is defined to be exogenous to the system. As knowledge is created in the external environment, it forms part of the total stock of knowledge in the external environment ( $S_{External}$ ).

$$S_{External} = \text{Integral}\ (R_{External} - \text{Depreciation rate of external knowledge})$$

**5-14**

As R&D is performed in the system, knowledge is absorbed from the external environment. The rate at which the system absorbs the knowledge is defined as the absorptive capacity. The model defines the absorptive capacity as the rate at which the system is able to absorb knowledge from the external environment. The quantity, quality, applicability and context of the knowledge ( $S_{External}$ ) in the external environment also impact on the system's ability to absorb the knowledge ( $R_{Absorbtion}$ ). This absorption rate is modelled through the following mathematical equation:

$$\text{Knowledge absorption rate}\ (R_{Absorbtion}) = R^{*}_{Absorbtion} * (\text{Fractional Change in } A_{Performance}(ABS))*(\text{Change in Absorptive capacity because of } S_{External})$$

**5-15**

With

$$\text{Change in absorptive capacity because of } S_{External} = \left(\frac{S_{External)}}{S^{*}_{External}}\right)^{\beta_7} \qquad \textbf{5-16}$$

The rate at which knowledge is absorbed feeds into the stock of knowledge that has been absorbed from the external environment ( $S_{Absorbed}$ ). The accumulation of the absorbed knowledge stock is depicted as follows:

$$S_{Absorbed} = \text{Integral}\ (R_{Absorbtion} - \text{Depreciation rate of absorbed knowledge})$$

**5-17**

The absorbed knowledge stock ( $S_{Absorbed}$ ) feeds back into the system equation for the change in system performance.

The second feedback loop whose output affects the system performance is the performance of R&D. The following section describes this loop in more detail.

### 5.5.6 Loop 2: the performance of R&D

The second reinforcing loop deals with the internal creation of knowledge in the system. The following stock and flow diagram displays the 'internal generation of knowledge' loop.

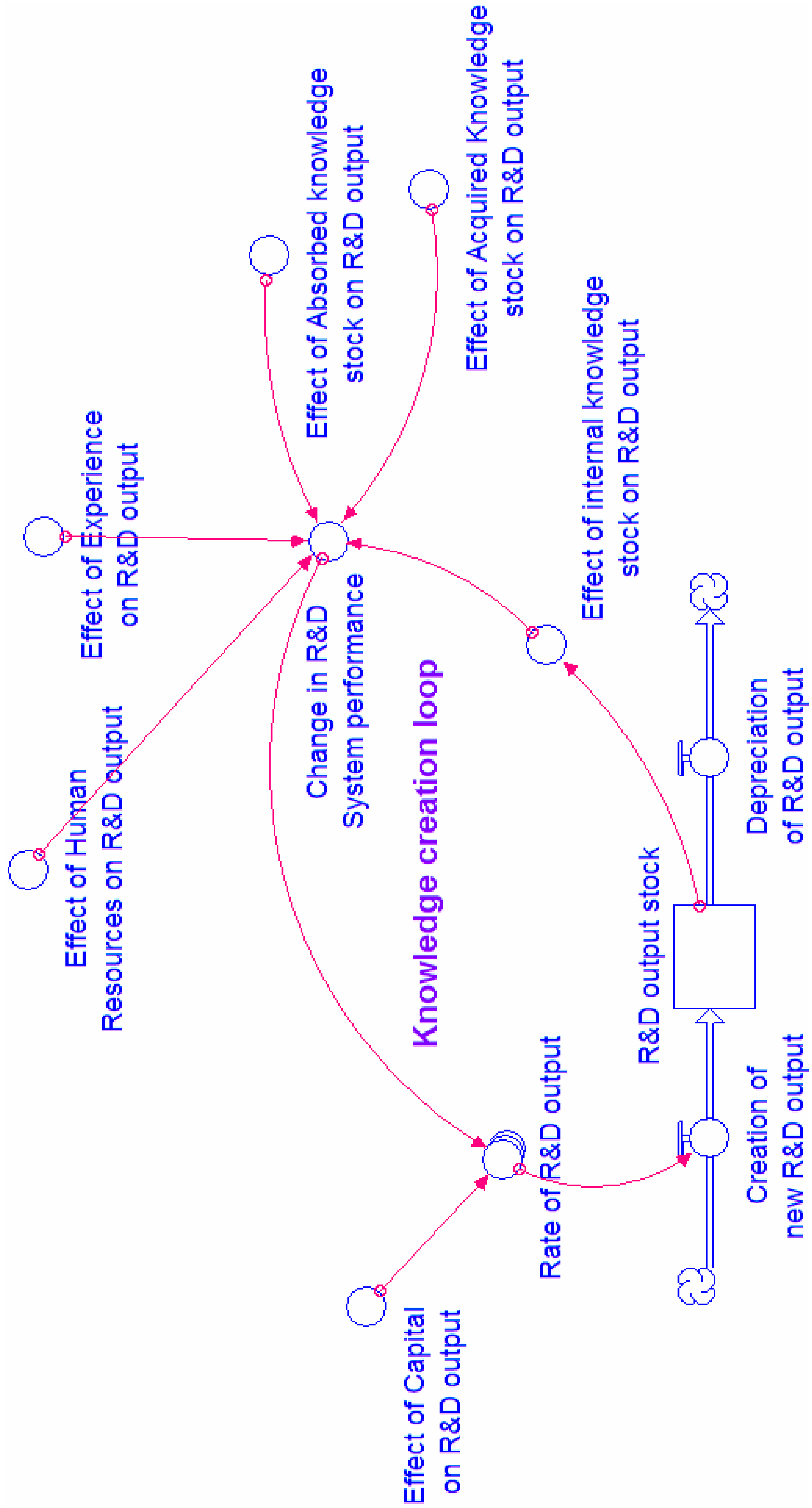



**Figure 5-14: Stock and Flow Diagram for the Performance of R&D**

In the development of the CLD, it was derived from theory that the rate of the creation of new knowledge $R_{R\&D}$ dependent on the stock of Human resources and different types of Knowledge contained in the system. The effect the knowledge has on the creation of knowledge is already integrated in the System performance parameter ( $A_{Performance}(R\&D)$ ).

R&D knowledge stock = Integral (rate of creation of R&D output - depreciation of R&D knowledge)

$$S_{R\&D} = \textbf{Integral} \; (R_{R\&D} \; \textbf{- depreciation of R\&D knowledge}) \qquad \textbf{5-18}$$

Performance of R&D (rate) = (Reference rate of R&D in 2001)* (Change in $A_{Performance}(R\&D)$ )

$$R_{R\&D} = R^{*}_{R\&D} * A_{Performance}(R\&D) \qquad \textbf{5-19}$$

Closing the reinforcing feedback loop, the R&D knowledge stock feeds back into the system performance computation equation.

### 5.5.7 Conclusion

This section identifies the basic elements of the R&D performing unit. The causal loop structure of an R&D performing sector was derived from theory, after which stock and flow diagrams were developed. The following is an integrated stock and flow diagram, depicting both feedback loops in the system:

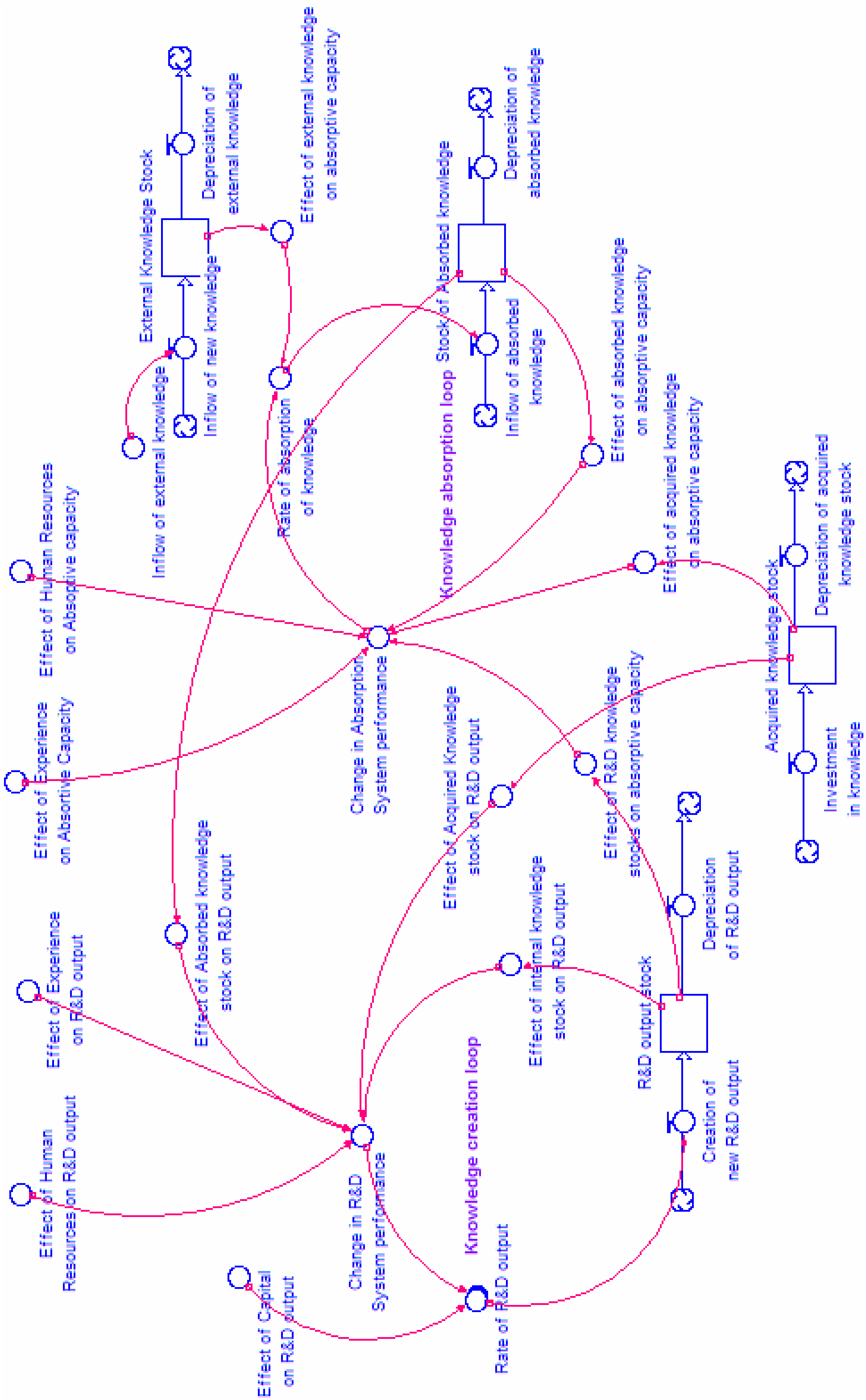



**Figure 5-15 Stock and Flow Diagram with Absorption and Creation of Knowledge**

The basic building block of the system has now been derived. As emphasised in the first section of this chapter, the system dynamics model developed is a generic model of R&D on a sector level. The following step in the development of a model of R&D in South Africa is therefore to apply and modify the conceptual model on South Africa's three R&D performing sectors.

## 5.6 Chapter Summary

This chapter documents the development and derivation of a system dynamics model of R&D activities in an R&D performing sector. The stock and flow diagram developed in this chapter follows directly from the CLD derived in the previous sections. The theoretical model developed will be applied to the three R&D performing sectors as discussed in previous sections of this chapter.

The following chapters document the data gathering, testing and calibration of the model of R&D in the South African system of innovation.

# 6 DATA GATHERING: DELPHI METHOD

## 6.1 The Delphi Method

The Delphi method is an established research methodology aimed specifically at exploring the expected future of novel and evolutionary phenomena. The technique obtains a group of experts' most reliable consensus of opinion (Dalkey & Helmer, 1963) by allowing them to express their own views on a topic, while taking into account the other participants' views by means of controlled feedback.

The method is based on the premise that well-informed individuals, drawing on their insights and on prior experience, are better equipped to predict the future than theoretical approaches or extrapolation of trends (Cuhls, 2003). The responses to a series of questionnaires are anonymous. Participants are also provided with a summary of opinions from a previous round before answering the next questionnaire. It is believed that such a consensus process will converge the group toward the 'best' response.

The midpoint of responses is categorised statistically using the median score. In each succeeding round of questionnaires, the range of responses by the panelists will presumably decrease and the median will move toward what is deemed to be the 'correct' answer.

The Delphi technique is well suited to situations where no or very limited historical data is available (Gupta and Clarke, 1996). The method is used mainly to assess long-term issues. As the procedure is aimed at identifying statements (topics) that are relevant for the future, it reduces the tacit and complex knowledge to a single statement and makes it possible to pass judgement.

Using the Delphi technique in conjunction with other methodologies, such as scenarios, technology lists, etc., might prove interesting. This specific method is of particular interest where subjective and complex judgements as opposed to precise quantitative results are of interest (Eto 2003).

It should however be noted that the Delphi technique would be unsuitable in more complex issues where the themes cannot be reduced much or where thinking and discussions in alternatives are the key objective (Eto 2003).

The chief users of the Delphi technique are companies, particularly strategy departments. The Delphi study is a formalised and traceable method that enjoys an amount of credibility with policy-makers. The method has been used in a vast number of technology forecasting studies (Mulder et al. 1996, Scott 2001, van Dijk, 1990), government foresight programmes, such as the UK Department of Trade and Industry's Foresight Programme (Department of Trade and Industry, 2000) and a study on German S&T policy issues (Cuhls, 2001).

### 6.1.1 Advantages of using the Delphi method

The anonymity of participants and the use of questionnaires avoid those problems commonly associated with group interviews, for example, specious persuasion or deference to authority, impact of oral facility, reluctance to modify publicised opinions as well as band wagon effects (Martorella, 1991, p.84).

The formalisation of the methodology, the amount of data, the number of experts involved and the fact that diverging opinions are partially hidden behind the main converging one, are all factors that contribute to the Delphi method being considered a popular and credible approach for policy makers. As the Delphi process forces group members to consider the problem under study logically and to provide written responses, the consensus reached by the group reflects reasoned opinions (Murry and Hammons, 1995).

Delphi surveys employ group decision-making techniques by involving experts in the field. Group decisions carry greater validity than those made by an individual (Brooks, 1979).

It may also be very difficult to bring a group of people together. Opinions and contributions can consequently be received from a group of experts who may be geographically separated from one another (Murry and Hammons, 1995).

The isolated generation of ideas also results in a high quantity of ideas (Delbecq and Van der Ven, 1974). Physically reading through the question forces one to think and respond with high quality ideas. As participants are forced to think of solution themselves and cannot react on answers from others in a group, the search behaviour is proactive (Delbecq and Van der Ven, 1974).

The judgements made in a Delphi study allows for analyses, rankings and priority-settings. As with other well-formalised methods, it forces people to think about the future. It provides participants with the opportunity to think in greater depth and to gather further information between the rounds.

### 6.1.2 Disadvantages of using the Delphi method

A number of disadvantages exist in applying the Delphi technique (Forlearn, 2006):

- Delphi studies are difficult to perform well. They are both fairly time-consuming as well as labour intensive and require external expert preparation. Delphi studies can therefore prove expensive
- care has to be taken over group effects. As in all panels or expert groups, the opinions will reflect the set of participants involve. A narrow set of criteria for these may thus lead to unrepresentative views or miss out important sources of knowledge. Single opinions that might be of special value are also pooled and normally ignored. Only the accumulated results are published to preserve anonymity. As anonymity has to be respected, it is often difficult to obtain reasons for dissenting answers later on
- some participants drop out during the process, especially after the first round. In addition, although further qualitative assessment of Delphi inquiry may produce

useful information, this step is often not carried out due to lack of time. It is often difficult to convince people to answer a questionnaire twice or more and incentives may be needed, e.g. providing the experts with the result of the study. The dropout rate increases after the second or third round, resulting in the majority of current studies being limited to preparation and two rounds

- because a topic generation procedure is needed, a Delphi survey is in essence always a mix of methods. Because the group never meets, there is also a degree of difficulty in assessing and utilising the expertise of the group fully (Murry and Hammons, 1995); and
- the danger also exists that greater reliance will be placed on the results than might be warranted. It is thus important to note that a consensus does not necessarily mean that the correct answer, opinion or judgement has been found. Instead, the method and results should be used as a means of structuring group discussion and raising issues for debate.

## 6.2 Selection of the Expert Panel

A crucial aspect of conducting a successful Delphi study is the selection of the respondents. Much care was consequently taken in recruiting the panel.

Dalkey, Rourke, Lewis & Snyder (1972) reported a definite and monolithic increase in the reliability of group responses with increasing group size. Reliability, with a correlation coefficient approaching .9, was found with a group size of 13. Debecq, Van de Ven & Gustafson (1975) suggest using the minimally sufficient number of respondents. Following these recommendations, a panel of 14 experts was selected for the Delphi study conducted in the research project.

Linstone and Turoff (1975) list applications where the heterogeneity of the participants must be preserved to assure the results' validity.

The experts for this study were selected with care with the specific goal in mind to ensure heterogeneity in terms of the role they play in the South African R&D system. Experts were thus selected to be representative of the three R&D performing sectors in the economy selection also took place on the basis of the different role their organisations play within the three sectors. Care was taken to include experts from all three of the R&D sectors in the South African R&D system namely the Higher Education System, Public sector and the Private sector.

- 5 individuals were selected from the Higher Education Sector. It was ensured that individuals were from different institutions namely University of Pretoria, Wits, Stellenbosch, and University of Cape Town. These individuals also play very different roles at each one of these universities
- From the Public sector 5 individuals were selected. All of these individuals hold very senior positions at their organizations (HSRC, DTI, SPII, NECSA, DST). The role of each of these organizations is very different within the South African R&D system.

- From the Private sector 5 individuals: Innovation Hub, 2 Entrepreneurs, Independent Innovation consultants, MD of a technology company. Many of these industry experts also play advisory roles to senior government officials.

A sensitivity analysis was conducted (See appendix I). It was found that no reason could be found to believe that sub-aggregations exist to adversely affect the reliability of the responses. It can be concluded that heterogeneity was found in the responses from the individuals in the expert panel.

The following lists the names of the experts selected to serve on the expert panel.

**Table 6-1: Expert Panel for Delphi Method**

| Name | Position | Sector |
|---|---|---|
| De Wet, Gideon | Academic and Innovation Expert (Stellenbosch) | HES |
| Marcus, Roy | Director of Da Vinci Institute (Wits) | HES |
| Pouris, A | Director of Institute of Technological Innovation at the University of Pretoria, Ministerial Advisor on Indicator for S&T | HES |
| Jeenah, Mohammed | University of Pretoria | HES |
| Kahn, Michael | Human Sciences Research Council, Head of R&D Survey | HES/Public |
| Potgieter, Johannes | Department of Trade and Industry. Head of strategy | Public |
| Suleman, Areef | SPII Champion | Public |
| Adams, Rob | Chair person Innovation Fund, CEO of NECSA | Public |
| Paterson, Adi | Director of DST | Public |
| Sawers, Jill | Manager at Innovation Hub | Industry |
| Botha, Anthon | Industry Expert: Techoscene – business consulting in innovation, technology and the commercialisation of innovation | Industry |
| Verhaege, Audrey | Independent Innovation Consultant | Industry |
| Aberdein, Darryl | Innovation consultant and Industry Expert | Industry |
| Bester, Coen | Entrepreneur, Senior executive at Brainworks | Industry |
| Ahlers, Johann | Defence sector expert (R&D), Scientific advisor of Minister f Defence | Industry |

## 6.3 Development of the Questionnaires

Delphi rounds of questionnaires continue until a predetermined level of consensus is reached or no new information is gained. This study was undertaken in two rounds. This approach was judged to be the correct balance between striving for a useful consensus and ensuring that a significant proportion of participants completed the study.

## 6.4 The First Round Questionnaire

The initial questionnaire was developed with a combination of closed and open-ended questions.

The questionnaire was aimed mainly at establishing the appropriateness of using patents and papers as a measure of R&D output in the South African R&D system. The open-ended questions posed requested respondents to expand on a list of alternative proxies to measure R&D output in the SA R&D system. An open-ended question regarding issues the South African R&D system will be facing in the next 20 years was also posed.

The following table contains the questions included in the first round survey sent to the panel of experts.

**Table 6-2: First Round Survey**

Delphi method Questionnaire: Round 1

Could you please answer the following questions? This should only take about 5-10 minutes of your time. If you could fill this form out and return it to me as soon as possible it will be greatly appreciated.

Sector: Higher Education Sector (HES)

1.1 Scientific paper output is a good measure of R&D output in the HES (1 agree - 6 disagree)
*Please answer the question by selecting a number indicating your opinion on a scale from 1 (you agree) to 6 (you disagree)*

1.2 What other proxies can be used for measuring the outputs gained from R&D in the South African HES?
*Please answer the question by naming some alternatives to measuring R&D output in the HES in SA.*

1.3 What are the general hurdles facing the SA HES R&D system in the next 20 years?
*Please answer the question by naming some possible threats to South Africa's R&D capacity in its HES.*

Sector: Public sector
2.1 Scientific paper output is a good measure of Basic and applied Research output in the Public Sector (1 agree - 6 disagree)
*Please answer the question by selecting a number indicating your opinion on a scale from 1 (you agree) to 6 (you disagree)*

2.2 Patent counts are a good measure of Experimental Development output generated in the Public Sector (1 agree – 6 disagree)
*Please answer the question by selecting a number indicating your opinion on a scale from 1 (you agree) to 6 (you disagree)*

2.3 What other proxies can be used for measuring the outputs gained from R&D in the SA Public sector?
*Please answer the question by naming some alternatives to measuring R&D output in the Public sector in SA.*

2.4 What are the general hurdles facing the SA Public sector R&D system in the next 20 years?
*Please answer the question by naming some possible threats to South Africa's R&D capacity in its Public sector.*

Sector: Private sector
3.1 Patent counts are a good measure of R&D output in the SA Private Sector (1 agree - 6 disagree)
*Please answer the question by selecting a number indicating your opinion on a scale from 1 (you agree) to 6 (you disagree)*

| |
|---|
| 3.2 What other proxies can be used for measuring the outputs gained from R&D in the SA Private sector? *Please answer the question by naming some alternatives to measuring R&D output in the Private sector in SA.*<br><br>3.3 What are the general hurdles facing the SA Private sector R&D system in the next 20 years? *Please answer the question by naming some possible threats to South Africa's R&D capacity in its Private sector.* |

Feedback from the questionnaires were analysed and used to develop a second questionnaire. The following section provides a brief discussion on the feedback received from the first round questionnaire.

### 6.4.1 Feedback from the first round questionnaire (HES)

#### 6.4.1.1 Round one: R&D output in the HES

The following is a graphic representation of the respondents' feedback on the applicability of scientific output counts as a proxy for R&D output in the South African HES. Respondents were asked to rate the following statement as indicated: **Scientific paper output is a good measure of R&D output in the HES (1 agree - 6 disagree).**

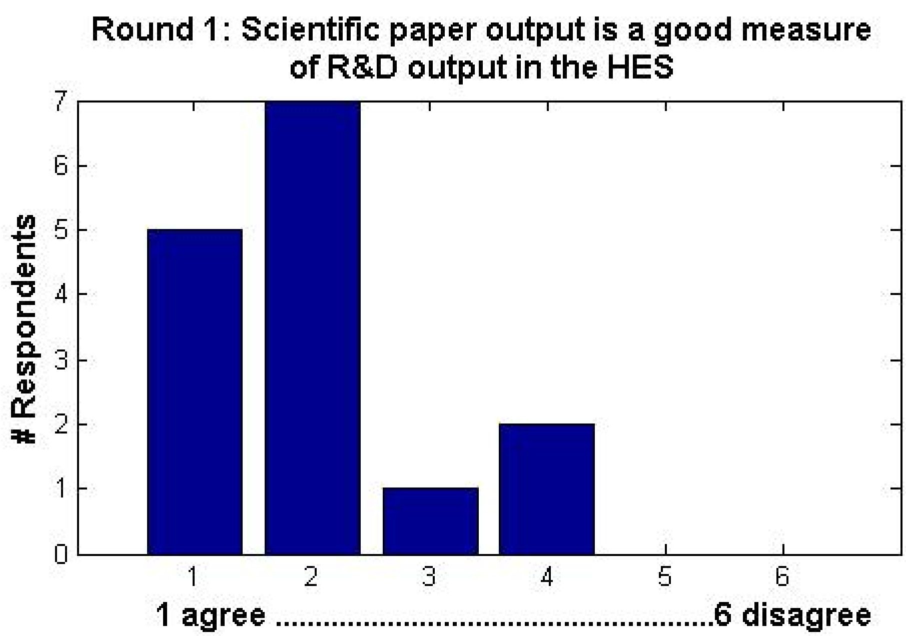



**Figure 6-1: Respondent Feedback on the Applicability of Scientific Output in the HES**

#### 6.4.1.2 Round one: Alternative proxies for R&D output in the HES

The following question was posed to the expert panel: **What other proxies can be used for measuring the outputs gained from R&D in the South African HES?**

The following is a list with categories and issues belonging to the categories developed from feedback received from the expert panel:

**Table 6-3: Proxies for the Measurement of R&D Output in the HES**

| Category | Proxies |
|---|---|
| R&D input as a measure of possible R&D outputs | • R&D expenditure in the HES<br>• Percentage funding sourced from private sector<br>• Percentage funding for R&D sourced from government sector<br>• Research grants attracted for R&D projects (both from South African as well as international sources) |
| Direct measures of R&D output | • Patents filed by universities<br>• Registered designs<br>• Conference papers<br>• Technology licences granted |
| Nature of R&D projects | • Percentage large multidisciplinary projects with multiple researchers from different fields of science<br>• Number of single researcher projects vs collaborative research projects (number of projects with more than one researcher) |
| Knowledge captured in equipment | R&D equipment capital stock value in Rand |
| The training of human resources as an output of R&D | • Number of Masters and PhD theses (as an R&D output)<br>• Training of human resources in terms of the number of PhD and Masters students as an output gained from R&D projects |
| Quality of R&D outputs | • Excellence and international recognition gained from R&D outputs, i.e. prizes won and key note address invitations for conferences<br>• Number of citations received by South African authors from ISI journals (can be used to identify centres of excellence) |
| Commercialisation of R&D | • Number of commercialisation projects<br>• Size (in Rand) of commercialisation projects<br>• ROI of commercialisation investment<br>• Venture capital available to HES<br>• Licence revenues (income generated from licensing)<br>• Spin-offs from R&D projects in HES |

#### 6.4.1.3 Round one: Hurdles faced in the HES (next 20 years)

The following question was posed to the expert panel: **What are the general hurdles facing the SA HES R&D system in the next 20 years?**

The following is a list with categories and issues belonging to the categories developed from feedback received from the expert panel:

**Table 6-4: Hurdles Facing the HES in the Next 20 Years**

| Issue Category | Examples of Issues Faced in this Category |
|---|---|
| Lack of funding for R&D in the sector | Poor prospects in terms of funding and the maintenance of R&D infrastructure |
| Nature of R&D projects | Lack of multidisciplinary research projects |
| Poor linkages pose a threat to future capacity and relevance of R&D system | • Poor linkages between researchers resulting in lack of knowledge sharing between researchers<br>• Poor linkages between researchers and industry: industrial participation low between HES and private sector |
| Inability to retain and rejuvenate human | • Poor prospects of the rejuvenation of human resources by, for instance, training new PhDs due to low enrolment in S&T courses in universities |

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| resources stock in the system | • Brain drain phenomenon with the following contributing factors:<br>❑ uncompetitive salaries offered to human resources in the system; and<br>❑ lack of career development opportunities for young researchers<br>• Students studying outside South Africa due to lower recognition of South African universities |
| Threat to future quality of human resources | • Threat to future quality of human resources – the quality of students studying in HES poor from poor secondary education system<br>• Quality of education deteriorating, resulting in a low quality of graduates leaving university<br>• Lack of good remuneration and career opportunities will cause the quality of researchers in the system to deteriorate |
| Current human resources policies and the possible affect on future R&D capacity: BEE | • Racial quotas and the lack of female and black human resources for R&D to reach representative work force<br>• Lack of funding for deserving students from the previously advantaged group |
| Difficulty of successful R&D policy alignment with national priorities | • Balancing local relevance with international cutting edge topics<br>• Balancing funding of R&D and training with basic needs delivery |
| Weak IP protection policies in HES | Weakness in IP protection policies of universities, causing them to loose out on millions of Rands in terms of intellectual property. |

### 6.4.2 Feedback from the first round questionnaire (public sector)

#### 6.4.2.1 Round one: R&D output in the public sector

The following is a graphic representation of the respondents' feedback on the applicability of scientific output as well as patent counts as a proxy for R&D output in the South African public sector. Respondents were asked to rate the following statements as indicated:

**Statement 1: Scientific paper output is a good measure of basic and applied research output in the public sector (1 agree - 6 disagree)**

**Statement 2: Patent output is a good measure of experimental development output in the public sector (1 agree - 6 disagree)**

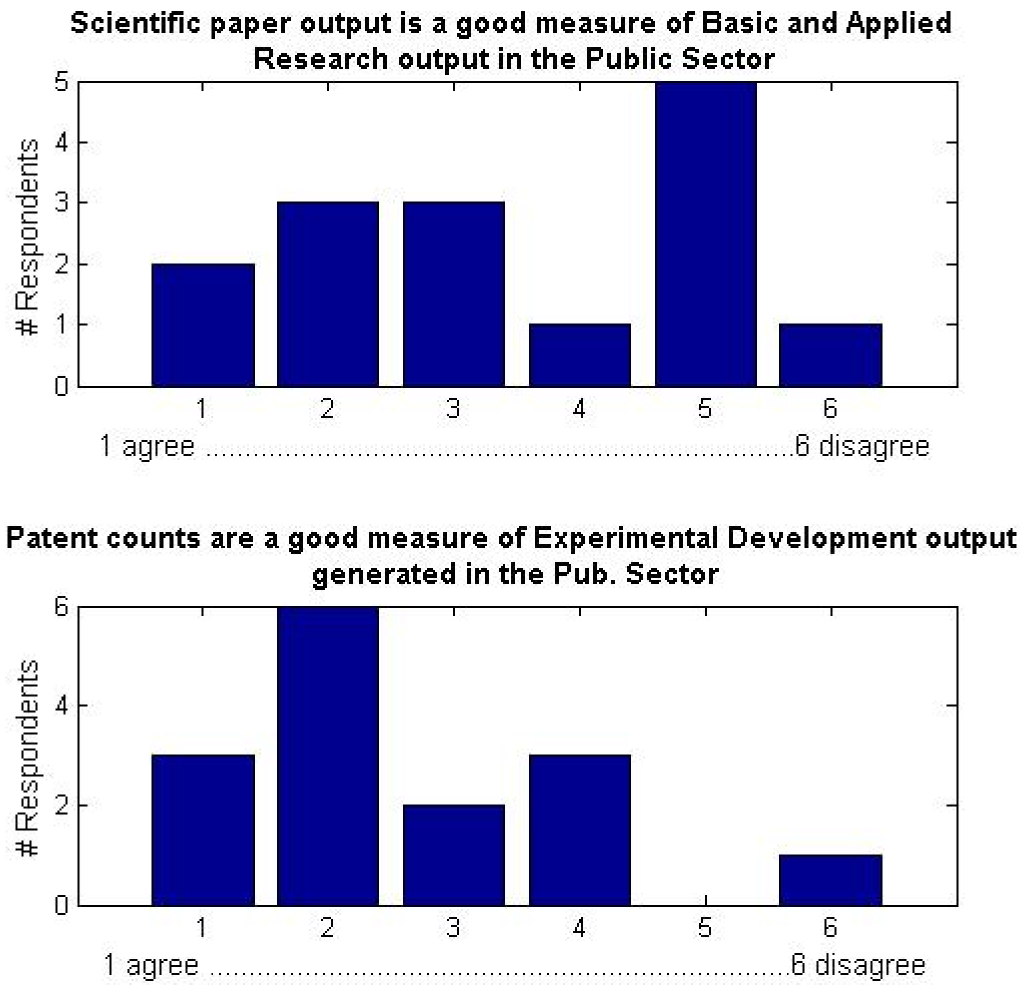


**Figure 6-2: Respondent Feedback: Indicators for R&D Output in the Public Sector**

Visual analysis yielded that the respondents did not reach consensus regarding the use of scientific paper output as a measure of basic and applied research output in the public sector. Two schools of thought were formed, where one group regarded scientific output as an appropriate proxy and the other did not.

The feedback gathered from the respondents therefore concluded that the majority of the respondents regards patent output as an appropriate proxy for experimental development output generated in the public sector.

#### 6.4.2.2 Round one: Alternative proxies for R&D output in the public sector

The following question was posed to the expert panel: **What other proxies can be used for measuring the outputs gained from R&D in the South African public sector?**

The following is a list with categories and issues belonging to the categories developed from feedback received from the expert panel:

**Table 6-5: Alternative Proxies for R&D Output in the Public Sector**

| Category | Proxies |
|---|---|
| R&D input as a measure of possible R&D outputs | • R&D expenditure in the public sector<br>• Percentage funding sourced from private sector<br>• Research grants attracted for R&D projects (from South African as well as international sources) |
| Direct measures of R&D output | • Registered designs<br>• Technology licences granted<br>• Synthesis reports<br>• Statistical surveys<br>• Prototypes<br>• Products<br>• Policy documents on policy changes and policies developed based on R&D results for the successful alignment with government direction setting and declared missions<br>• Number of knowledge transfer conferences |
| Knowledge captured in equipment | R&D equipment capital stock (value in Rand) |
| Commercialisation success of R&D | • Number of commercialisation projects<br>• Size (in Rand) of commercialisation projects<br>• ROI of commercialisation investment<br>• Licence revenues (income generated from licensing)<br>• Spin-offs from R&D projects in public sector<br>• Percentage of contract income in any financial year from new products/services created in the past two years or an equivalent measure |
| Transfer of technology as an output of R&D projects in the public sector | • Number of products developed in private sector using technology developed in projects at science councils<br>• Number of collaborative projects with industry |
| Linkages | • Number of public/private sector partnerships in R&D domain<br>• Number of collaborative projects with international partners |

#### 6.4.2.3 Round one: Hurdles faced in the public sector over the next 20 years

The following question was posed to the expert panel: **What are the general hurdles facing the SA public sector R&D system in the next 20 years?**

The following is a list with categories and issues belonging to the categories developed from feedback received from the expert panel:

**Table 6-6: Hurdles Facing the Public Sector in the Next 20 Years**

| Issue Category | Examples of Issues Faced in this Category |
|---|---|
| Lack of government funding to public sector to develop R&D and technology platforms | • Lack of funding. Government funding should be adequate to develop technology platforms for transfer to the private sector.<br>• Not supporting a competitive R&D infrastructure: Earning income from consultancy work should have lower priority and not be used to sustain research institutions.<br>• Too much bureaucracy in administration of system and funding to |

| | |
|---|---|
| | research projects |
| Nature of R&D projects | Lack of multidisciplinary research projects |
| Inability to retain and rejuvenate the researchers stock in the system | • Losing human resources to private sector or to other countries; losing human resources through the brain drain phenomenon<br>• Lack of adequate rewards systems – uncompetitive salaries<br>• Lack of rejuvenation of human resources – low numbers of graduates are interested in science as a career |
| Deterioration of quality of human resources working in R&D | • Poor quality of graduates entering the system<br>• Lack of good remuneration and career opportunities will cause the quality of researchers in the system to deteriorate<br>• Inability to overcome mentorship across cultures |
| Current BEE policies will have a negative affect on quality and R&D capacity | Representativity: Racial quotas rather than competence as functional goals of policy instruments. |
| Lack of direction and leadership in science policy | • Lack of coherent NIS, based on credible foresight.<br>• Continuous refocusing on the short term, not having a long range strategy ('flavour of the month' approach followed by government, e.g. will want to shift R&D focus to alternative sources for energy after recent problems at Eskom) |

### 6.4.3 Feedback from the first round questionnaire (private sector)

#### 6.4.3.1 Round one: R&D output in the private sector

The following is a graphic representation of the respondents' feedback on the applicability of patent counts as a proxy for R&D output in the South African private sector.

Respondents were asked to rate the following statements as indicated:**Patent output is a good measure of R&D output in the Private sector (1 agree - 6 disagree)**

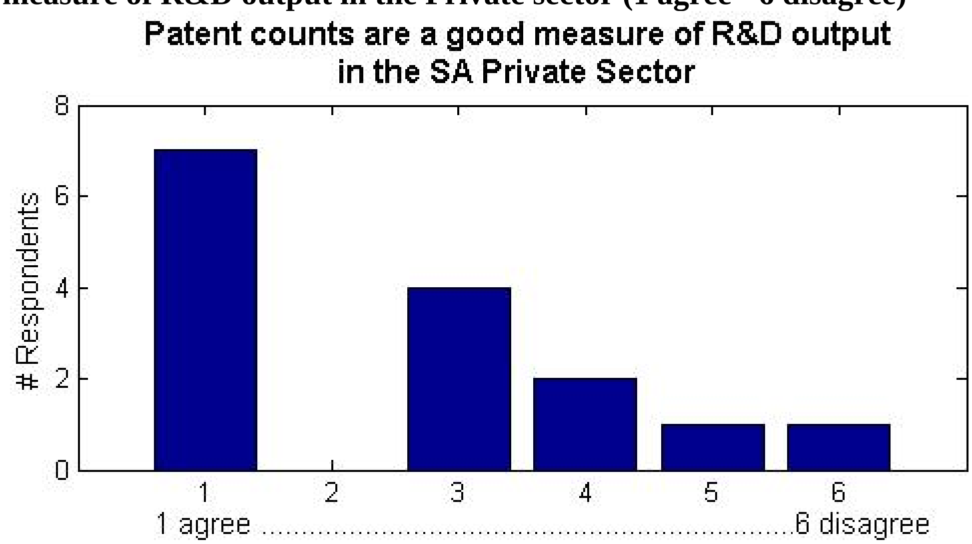


**Figure 6-3:** **Patents Counts as a Measure of R&D Output Created in the Private Sector**

The feedback gathered from the respondents concluded that the majority of the respondents regard patent output as an appropriate proxy for experimental development output generated in the private sector.

#### 6.4.3.2 Round one: Alternative proxies for R&D output in the private sector

The following question was posed to the expert panel: **What other proxies can be used for measuring the outputs gained from R&D in the South African private sector?**

The following is a list with categories and issues belonging to the categories developed from feedback received from the expert panel:

**Table 6-7: Alternative Proxies for R&D Output in the Private Sector**

| Category | Proxies |
|---|---|
| R&D funding and the availability of funding as a measure of possible R&D outputs | • R&D expenditure in the private sector<br>• Research grants attracted for R&D projects from both South African as well as international sources)<br>• Innovation budget of firms<br>• Growth of venture capital industry |
| Direct measures of R&D output | • Registered designs<br>• Technology licences granted<br>• Prototypes |
| Innovation outputs as a result of R&D | • New products, e.g. less than one year old, as a percentage of total product offering<br>• Number of new product launches and significant upgrades<br>• Ratio of own developed products/processes to licensed products/processes |
| Knowledge captured in equipment | R&D equipment capital stock value in Rand |
| Commercialisation success of R&D | • Growth in market share locally and globally attributed to innovation<br>• Global market leadership<br>• International sales<br>• Growth in export sales<br>• Percentage of business income in any financial year from new products/services created in the past two years<br>• Number of commercialisation projects<br>• Size (in Rand) of commercialisation projects<br>• ROI of commercialisation investment<br>• Royalties received from intellectual property<br>• Spin-offs from R&D projects in private sector<br>• Jobs created through R&D projects |
| Linkages and flows | • Inward knowledge intensive FDI<br>• Number of public/private sector partnerships in R&D domain<br>• Number of collaborative projects with international partners |

#### 6.4.3.3 Round one: Hurdles faced in the private sector over next 20 years

The following question was posed to the expert panel: **What are the general hurdles facing the SA private sector R&D system in the next 20 years?**

The following is a list with categories and issues belonging to the categories developed from feedback received from the expert panel:

**Table 6-8: Hurdles Facing the Private Sector over the Next 20 Years**

| Issue Category | Examples of Issues Faced in this Category |
|---|---|
| Lack of research culture in SA | • Companies do not realise the importance and benefits of R&D to maintain competitiveness<br>• South African mindset: to import value added rather that to add the value through R&D. Some of our largest companies are just distribution and sales centres for American and Japanese companies. |
| Lack of funding and fiscal incentives from government to foster R&D culture in companies | • Lack of R&D investment incentives<br>• Lack of tax incentives from government – financial support to convince companies to take risk and help them overcome their short term against long term perspective.<br>• Better tax breaks in other countries. Globalisation of research leading to loss of local capacity<br>• Lack of export incentives<br>• Lack of support for commercialisation of R&D<br>• Lack of funding for local R&D by multinationals |
| Nature of R&D projects | Lack of multidisciplinary research projects |
| Inability to retain and rejuvenate the researchers stock in the system | • Lack of rejuvenation of human resources: low supply of skilled R&D personnel – not enough science and technology graduates to conduct R&D<br>• Lack of adequate rewards systems - uncompetitive salaries<br>• Losing human resources to private sector or to other countries – retention of HR through brain drain phenomenon |
| Deterioration of quality (skill level) of human resources working in R&D | • Poor quality of graduates entering the system<br>• Poor quality of graduates<br>• Lack of knowledge and business intelligence<br>• Management of technology skills |
| Current BEE policies will have a negative affect on quality and R&D capacity. | • Representativity: racial quotas rather than competence as functional goals of policy instruments<br>• BEE legislation – many international companies will rather pull out that to share IP through shareholding.<br>• Economic empowerment sapping investment funds from company profits |
| Poor linkages | • Linkages between research and development not in place: private sector will not invest in R&D projects where the commercial potential is not obvious. Government thus needs to lead in strategic development projects to develop technology platforms from which the private sector can develop new products and processes.<br>• Inability to find global distribution partners – remoteness of market in world terms. We need to develop our manufacturing capability and value-add capability internationally |
| Lack of direction and leadership in science policy | • Lack of competitive strategies and leadership<br>• Lack of coherent NIS, based on credible foresight, and consequently 'deepening' of the technology colony situation |
| Communication infrastructure | Bandwidth restrictions |

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|---|---|
| General | Crime/stability in the country |

## 6.5 The Second Round Questionnaire

The second round questionnaire was developed from the feedback received from the first round. See Appendix F for the second round questionnaire. The responses returned from the first round were analysed and applied for the development of the second round questionnaire.

In the second round, feedback was provided regarding the outcome of the first round. Respondents also had the opportunity revise some of their responses made in the first round.

Further analysis was done regarding the open-ended questions posed in the round one survey. After categorising contributors' responses, respondents were asked to rate the seriousness and criticality of hurdles facing the R&D system of South Africa identified in the first round.

**Table 6-9: Description of the Ranking Criteria for Issues Ranked by the Experts**

| Rank | Description |
|---|---|
| 1 | Critical issue |
| 2 | Serious issue |
| 3 | Issue |
| 4 | Possible issue |
| 5 | Unlikely issue |
| 6 | Issue does not exist |

The standard deviation is a measurement of the variability in a population. In a normal distribution, 68% of the scores fall within one standard deviation above and one standard deviation below the mean. For the purpose of this study, a decision was made on the level of consensus reached in terms of the standard deviation as described in the following table:

**Table 6-10: Decision Criteria for the Level of Consensus Reached in the Delphi Study**

| Standard Deviation | Level of Consensus Achieved |
|---|---|
| $0 \leq X < 1$ | High level |
| $1 \leq X < 1.5$ | Reasonable/fair level |
| $1.5 \leq X < 2$ | Low level |
| $2 \leq X$ | No consensus |

The following sections describe the feedback gathered from the panel of experts in the Delphi study.

The open-ended questions regarding other proxies that could be used for measuring the outputs gained from R&D in the South African HES was not surveyed further in the Delphi study. The questions were posed to respondents mainly to compile a list of possible alternatives to measure R&D output in the South Africa R&D system.

### 6.5.1 Feedback from the second round questionnaire (HES)

#### 6.5.1.1 Round two: R&D output in the HES

Respondents had the opportunity revise their opinions of the applicability of using scientific output as a measure of R&D output in the HES. As one respondent dropped out from the first round to the second, his/her first round answer was used in the second. The revised version of the expert opinions (after the second round) is represented in the following graph:

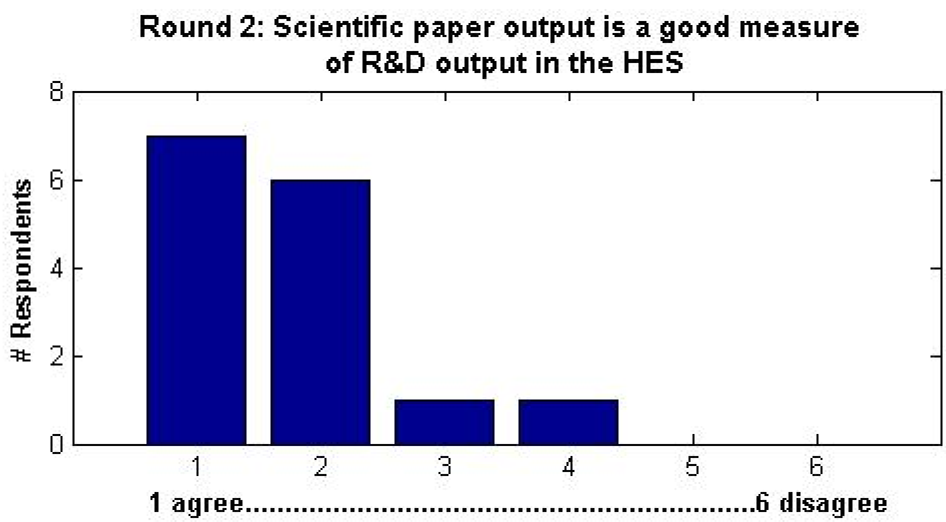



**Figure 6-4: Second Round Feedback: Measure of R&D Output in the HES**

A further analysis was done to facilitate a comparison of the movement of opinion and the level of agreement of the group. The following graph is a representation of the movement of group opinion, measured in terms of the mean, and the level of consensus, measured in terms of the standard deviation, from round one to round two. It is noted that both group opinion and the level of agreement have moved slightly.

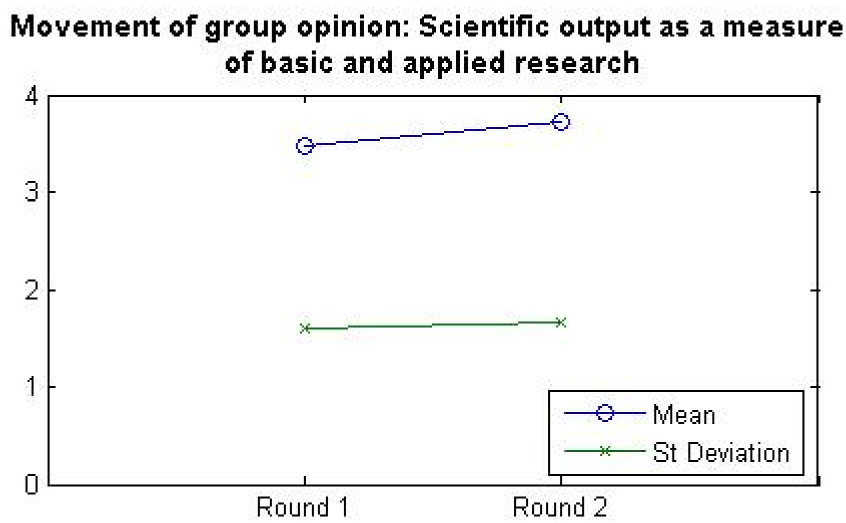



**Figure 6-5: Group Opinion for Using Papers to Measure R&D Output in the HES**

It can be concluded that a relatively high level of consensus was reached (standard deviation = 0.85), which indicates that the experts in general agree that scientific paper output is a good measure of R&D output generated in the South African HES (mean = 1.73).

Based on the feedback gained from the expert panel, it can therefore be concluded that scientific paper output can be used as a proxy for R&D output in the development of the HES model.

#### 6.5.1.2 Round two: Hurdles faced in the HES over the next 20 years

The following question was an open-ended question posed to the expert panel in the first round survey: **What are the general hurdles facing the SA HES R&D system in the next 20 years?**

A list of issues was compiled from the experts' responses in the first round.

In the development of the second round survey the ideas generated in the first round questionnaire were categorised. In the second round survey, respondents were asked to rate issue categories on a scale from 1 to 6 where 1 indicates that it is a critical issue and a rating of 6 indicates that the issue does not exist. The following is a brief summary of the group opinion after the second round:

**Table 6-2: Summarised Issues Rankings for R&D in the HES**

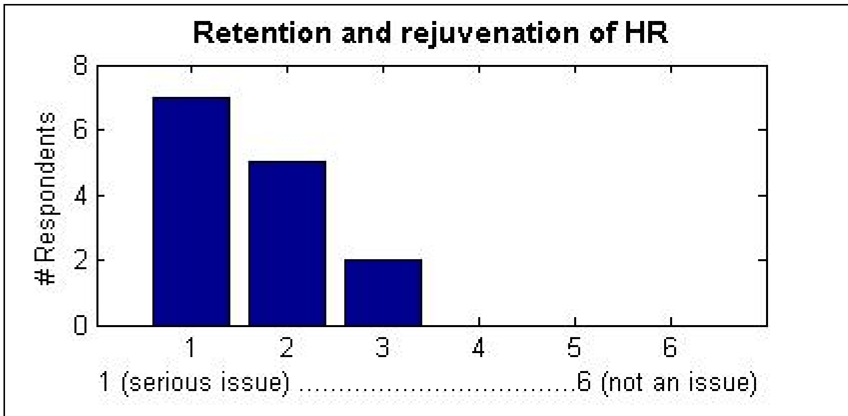
| Issue Category | Median | Mean | Mode | St. Dev |
|---|---|---|---|---|
| **1. Inability to retain and rejuvenate human resource** | 1.50 | 1.64 | 1.00 | 0.72 |

| | | | | |
|---|---|---|---|---|
| **stock in the system** | | | | |
| **2. Lack of funding for R&D in the HES** | 2.00 | 2.29 | 2.00 | 1.10 |
| **3. The lack of female and black researchers for R&D to reach representative work force** | 2.00 | 2.71 | 2.00 | 1.48 |
| **4. The deterioration of quality of human resources working in R&D in the sector** | 2.50 | 2.43 | 1.00 | 1.12 |
| **5. Poor linkages pose a threat to future capacity and the relevance of R&D performed in the system** | 2.50 | 2.43 | 3.00 | 0.82 |
| **6. Lack of multidisciplinary research projects** | 3.00 | 3.29 | 2.00 | 1.53 |
| **7. Difficulty of successful R&D policy alignment with national priorities** | 3.00 | 3.29 | 3.00 | 0.96 |
| **8. Weak IP protection policies in HES** | 3.00 | 3.36 | 3.00 | 1.34 |
| **9. Inadequate funding of equipment** | 3.50 | 3.14 | 4.00 | 0.99 |

The issues listed in Table 6-2 will be discussed in more detail in the following sections.

*1. Inability to retain and rejuvenate human resources stock in the system*

This question relates to poor prospects of the rejuvenation of human resources due to issues, such as low enrolment in S&T courses in universities, the low number of PhDs graduating from universities as well as the notorious brain drain phenomenon. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

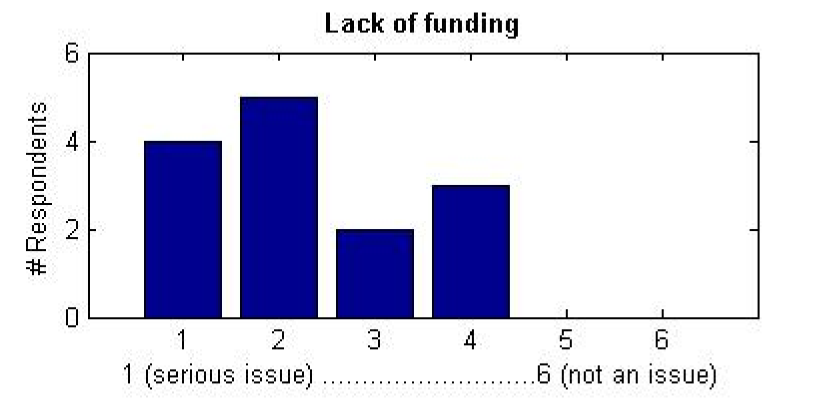



**Median: 1.5**
**Mean: 1.64**
**Mode: 1**
**Stdev: 0.72**

A high level of consensus (standard deviation of 0.72) was achieved regarding this issue. The aggregated expert opinion is that the South African HES's inability to retain and rejuvenate the human resources stock in the system will pose a major hurdle to the system in the next 20 years. A substantial percentage of the respondents (50%) rated this as a critical issue (rank = 1) facing the HES R&D system.

*2. Lack of funding for R&D in the HES*

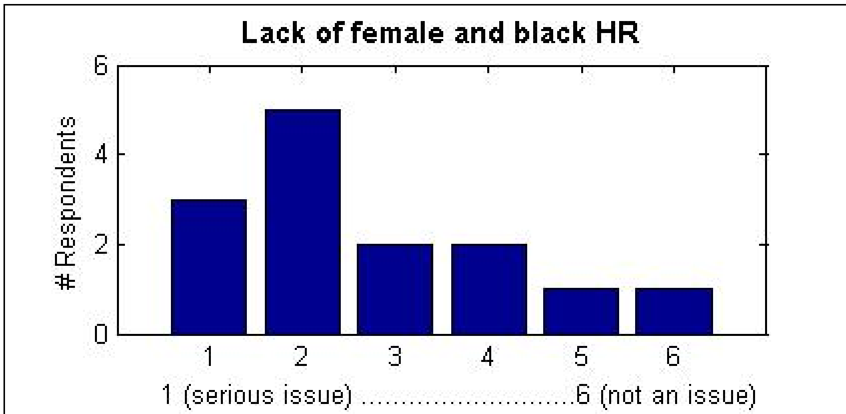
This issue relates to poor prospects in terms of funding for the maintenance of the R&D infrastructure in the HES in the next 20 years. The following is a graphic representation of feedback received from the expert panel regarding the perceived issue's level of criticality:




**Median: 2**
**Mean: 2.29**
**Mode: 2**
**Stdev: 1.10**

A reasonable level of consensus (standard deviation of 1.10) was achieved regarding this issue. Experts reached a reasonable level of agreement regarding a lack of adequate funding for R&D projects over the next 20 years. The aggregated expert opinion is that the lack of enough funding for R&D projects will be a major issue affecting the system in the next 20 years.

*3. The lack of female and black researchers for R&D to reach representative work force*
This issue relates to a perceived hurdle posed to the sector in the next 20 years regarding the persisted shortages of female and black researchers necessary to reach a representative work force. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:



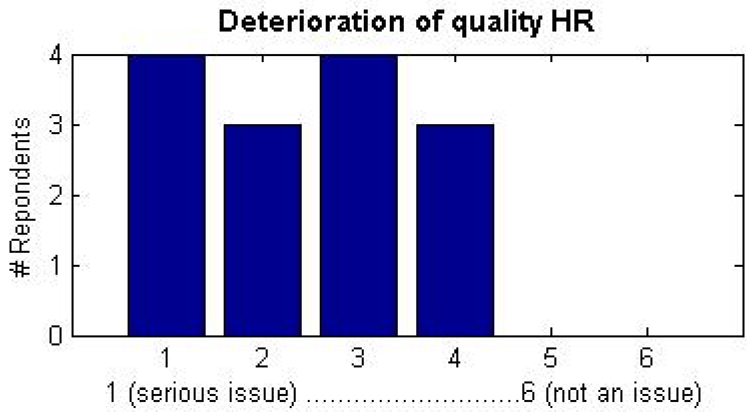

**Median: 2**
**Mean: 2.71**
**Mode: 2**
**Stdev: 1.48**

A low level of consensus was achieved regarding this issue with a standard deviation of 1.48. Experts fail to agree wholly on whether shortages in female and black researchers will pose a hurdle to the R&D sector in the following 20 years. Although the mean computed expert opinion is fairly low at 2.71, a substantial amount of experts rated this as an important issue (8 experts rated it to be of level 1 and 2). This indicates that the lack of female and black researchers to reach a representative work force might remain a hurdle to the system in years to come.

*4. There deteriorating quality of human resources working in R&D in the sector*

This question relates to a perceived threat to the future level of quality of human resources working in the HES. This threat could stem from multiple reasons, including, amongst others, poor quality students entering the HES, a perceived deterioration of the quality of education, resulting in a low quality of graduate leaving university and a lack of good remuneration and career opportunities, which could result in the level of quality of researchers in the system deteriorating.

The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality.

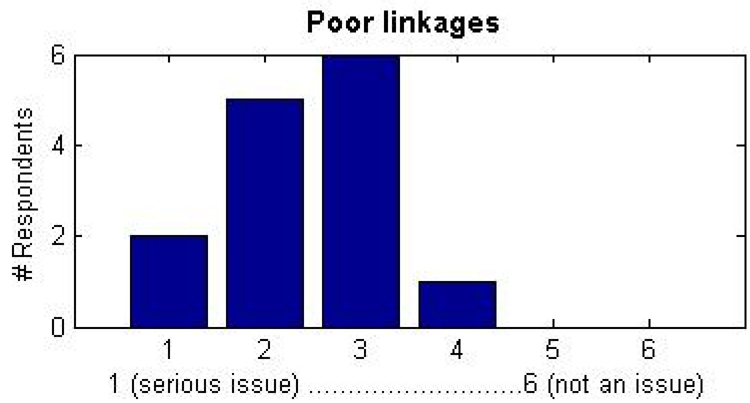



**Median: 2.50**
**Mean: 2.43**
**Mode: 1**
**Stdev: 1.12**

A reasonable level of consensus was achieved with a standard deviation of 1.12. Expert opinion indicates that the HES faces a deterioration of the quality of human resources working in the sector. A substantial amount of the respondents (50%) rated this as a critical issue or major issue (ranking 1 or 2) facing the HES in the next 20 years.

*5. Poor linkages pose a threat to future capacity and the relevance of R&D performed in the system*

This perceived issue relates to poor linkages between researchers and the industry, resulting in low industrial participation between the HES and the private sector. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

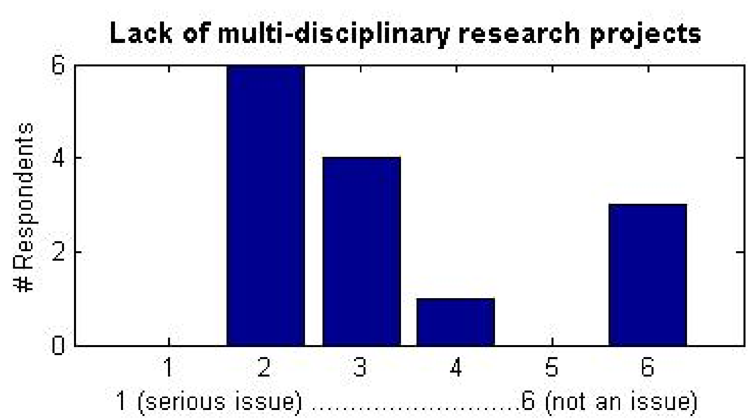



**Median: 2.50**
**Mean: 2.43**
**Mode: 3**
**Stdev: 0.82**

A high level of consensus was achieved regarding this issue with a standard deviation of 0.82. Although some of the respondents rate the issue as critical (2 respondents rated it to be of level 1), 11 of the respondents rated the issue to be of level 2 and 3 of criticality. Such a rating indicates that although the issue was not perceived as highly critical, it remained an area of concern that should receive the necessary attention to ensure the future relevance of R&D performed in the sector.

*6. Lack of multidisciplinary research projects*

This issue relates to a perceived hurdle posed to the sector in the next 20 years regarding a lack of multidisciplinary research projects. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

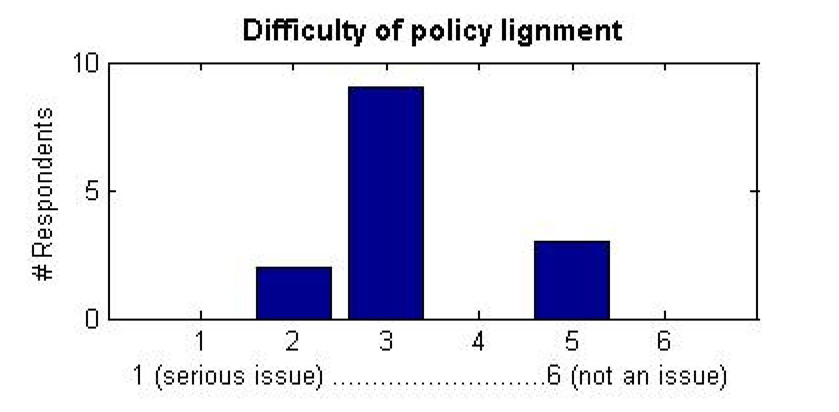



**Median: 3**
**Mean: 3.29**
**Mode: 2**
**Stdev: 1.53**

A low level of consensus was achieved regarding this issue with a standard deviation of 1.53. There seems to be two schools of thought regarding this issue. Three respondents believed this not to be an issue at all. A substantial amount of the respondents, i.e. ten, however agreed that this should be viewed as an area of concern and that a lack of multidisciplinary research projects might pose some degree of problems to the R&D system in the following 20 years to come.

*7. Difficulty of successful R&D policy alignment with national priorities*

Respondents were asked to provide their opinion regarding the criticality of issues of the effect that balancing funding of R&D and training with basic needs delivery will have on the system in the next 20 years. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

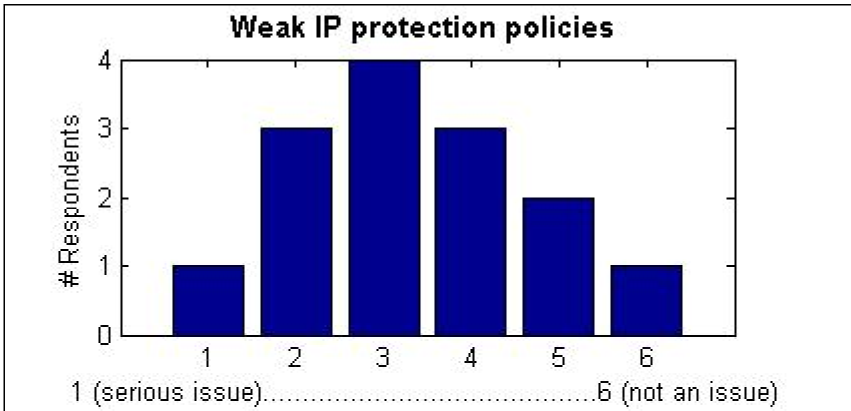



**Median: 3**
**Mean: 3.29**
**Mode: 3**
**Stdev: 0.96**

A high level of consensus was achieved with a standard deviation of 0.96. Respondents agreed that although this was not a critical issue, it had to be viewed as an area of concern.

*8. Weak IP protection policies in HES*

Respondents were asked to comment on the level of criticality of a perceived issue that the HES has weak IP protection policies of universities, thus causing them to loose out on millions of Rands. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

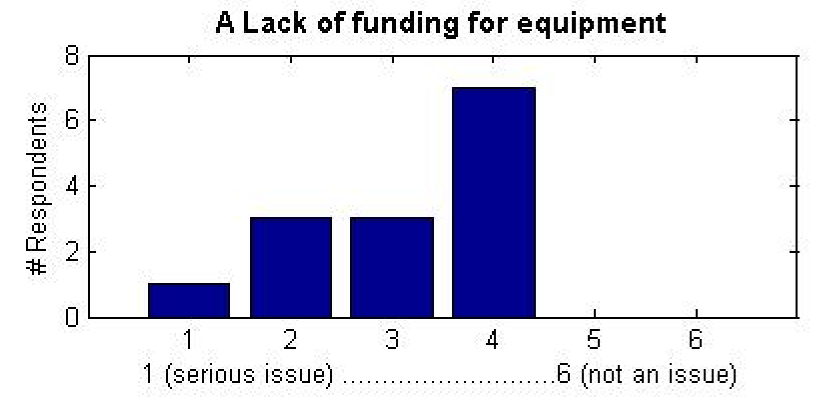



**Median: 3**
**Mean: 3.36**
**Mode: 3**
**Stdev: 1.34**

A fair level of consensus was reached with a standard deviation of 1.34. Respondents agreed to some extent that the IP policies of universities should be seen as an area of concern (mean of 3.36).

*9. Inadequate funding of equipment*

Respondents were asked to comment on the level of criticality of a perceived issue that there will be a shortage of funding for research equipment in the HES in the next 20 years. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

| | |
|---|---|
|  | **Median: 3.5**<br>**Mean: 3.14**<br>**Mode: 4**<br>**Stdev: 0.99** |



A reasonably high level of consensus was reached with a standard deviation of 0.99. The experts seemed to agree to a large extent that the inadequate funding of equipment should not pose a major hurdle to R&D in the HES over the next 20.

### 6.5.2 Feedback from the second round questionnaire (public sector)

Respondent had the opportunity to revise their opinions of the applicability of using scientific output and patents as a measure of R&D output in the public sector.

#### 6.5.2.1 Round two: Basic and applied research in the public sector

Respondent had the opportunity to revise their opinions of the applicability of using scientific output as a measure of basic and applied research output in the public sector. The revised version of expert opinions (after the second round) is graphically represented in the following graph:

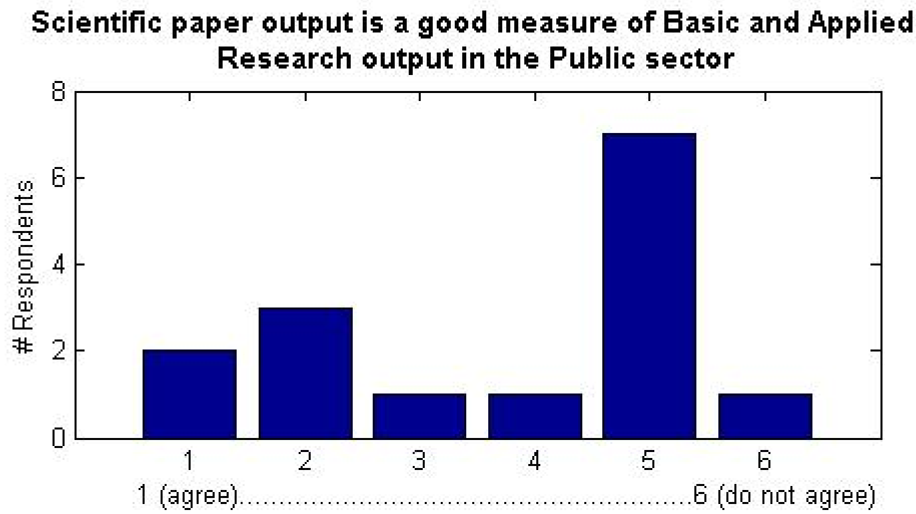



**Figure 6-6: Second Round Feedback: Measure of Basic and Applied Research in the Public Sector**

A further analysis was done to facilitate a comparison of the movement of opinion and the level of agreement of the group. The following graph provides a graphic representation of the movement of group opinion (measured in terms of the mean) and the level of consensus (measured in terms of the standard deviation) from round one to round two.

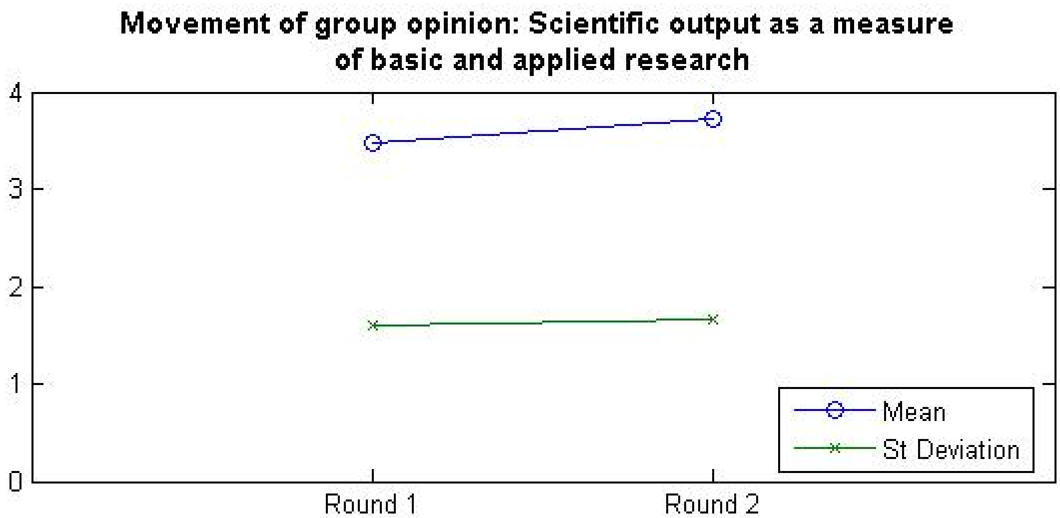



**Figure 6-7: Group Opinion: Measure for Basic and Applied Research Output in the Public Sector**

It can be concluded that a slightly higher level of consensus was reached (standard deviation =1.59 to 1.65) after the second round. On the Likert scale of 1 to 6, where 1 indicates that the responded agrees with the statement and where 6 indicate that the respondent disagrees, the mean was 3.73. The mean moved from 3.47 to 4.73 after the second round.

The mode and median for the feedback gained from the expert panel was both 5, which indicates that the aggregated expert opinion is that scientific publication output is not an adequate measure of basic and applied research output in the public sector.

However, it appears that there might be two schools of thought in the expert group. A substantial number of the experts, i.e. six, agreed to some extend that scientific publication output could be used as a proxy for basic and applied research output in the public sector.

#### 6.5.2.2 Round Two: Experimental development in the public sector

Respondent had the opportunity to revise their opinions of the applicability of using patent output as a measure of experimental development in the public sector. The second round responses received from the expert panel is represented graphically in the following figure:

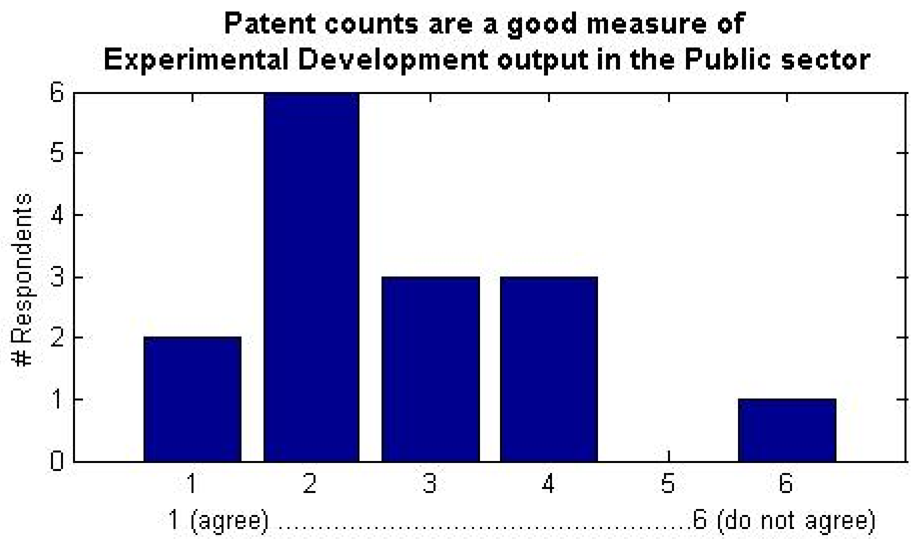



**Figure 6-8: Measure of Experimental Development Output in the Public Sector**

The responses yielded that the mode is 2, which indicates that the respondents view this measure as a valid proxy for measuring experimental development output in the public sector. From the 12 respondents, only four ranked above 3, which would indicate that they do not agree. We can therefore conclude that patent output is a relatively good measure of experimental development output in the South African public sector. This approach naturally also has its weaknesses, which is reflected in the mean rating of 2.92 by the expert panel.

The comparison of movement of opinion and the group's level of agreement was also analysed further. The following graph represents the movement of group opinion, measured in terms of the mean, and the level of consensus, measured in terms of the standard deviation, from round one to round two.

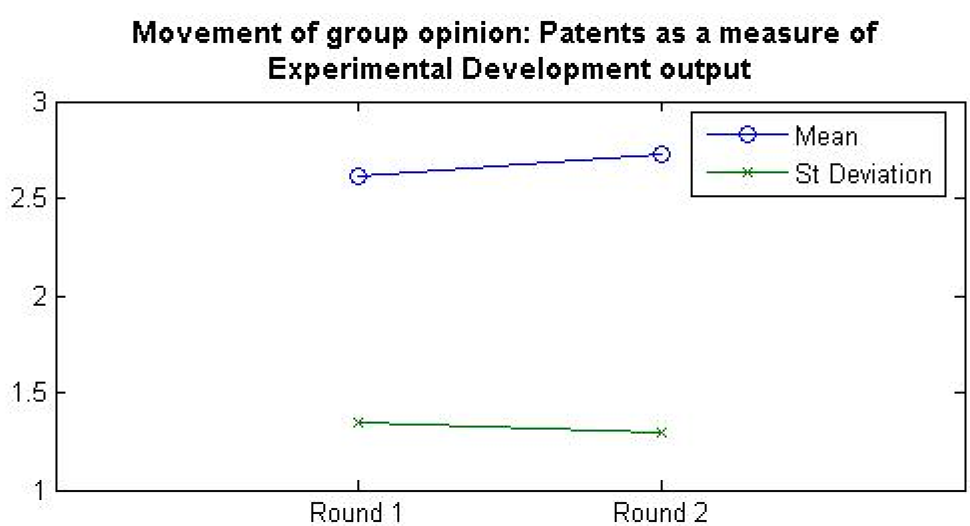


**Figure 6-9: Group Opinion: Experimental Development Output in the Public Sector**

The graph concludes that the group opinion has shifted from a mean ranking of 2.61 to 2.73. By the second round, a slightly higher level of agreement was reached with a standard deviation moving from 1.35 to 1.29. We can therefore conclude that the expert panel agrees to a reasonable level that patent output is an acceptable measure of R&D output generated in the public sector. The statement thus holds that patent output could be an appropriate proxy for experimental development output in the public sector model.

#### 6.5.2.3 Round two: Hurdles faced in the public sector (next 20 years)

The following question was an open-ended question in the first round survey: **What are the general hurdles facing the South African public sector R&D system in the next 20 years?** A list of issues was compiled from the experts' responses in the first round.

The ideas generated in the first round questionnaire were categorised when developing the second round survey. In the second round survey, respondents were asked to rate issue categories on a scale from 1 to 6, where 1 indicates that it is a critical issue and a rating of 6 indicates that the issue does not exist.

**Table 6-3: Summarised Issues Rankings for R&D in the Public Sector**

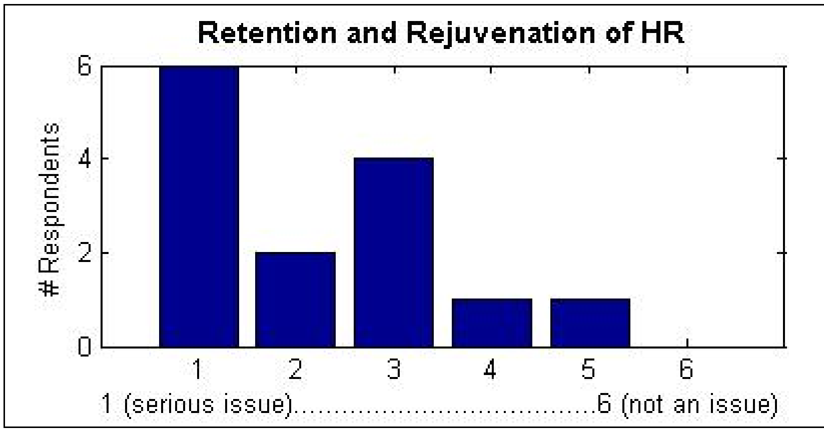
| Issue Category | Median | Mean | Mode | St. Dev |
|---|---|---|---|---|
| **1. Inability to retain and rejuvenate the researchers stock in the system** | 2 | 2.21 | 1 | 1.26 |
| **2. Lack of government funding to the public sector to develop R&D and technology platforms** | 2 | 2.43 | 2 | 1.12 |
| **3. Deterioration of quality of human resources working in R&D** | 2 | 2.43 | 2 | 1.12 |
| **4. A lack of direction and leadership in science policy** | 2 | 2.79 | 2 | 1.42 |
| **5. Current BEE policies having a negative effect on quality and R&D capacity** | 2.5 | 2.86 | 1 | 1.64 |

Table 6-3: indicates that all the issues raised have a median of 2 and a mean above 2 and below 3. The expert panel thus rated all these issues as relevant to some extent to the future of the public sector R&D system. The issues listed in Table 6-3: are discussed in more detail in the following sections.

*1. Inability to retain and rejuvenate the researchers stock in the system*

This perceived issue relates to the public sector's inability to retain and rejuvenate the human resources stock due to any of the following issue raised by the respondents: losing HR through brain drain phenomenon; low numbers of graduates interested in science as a career; and the lack of adequate rewards system in the public sector.

The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

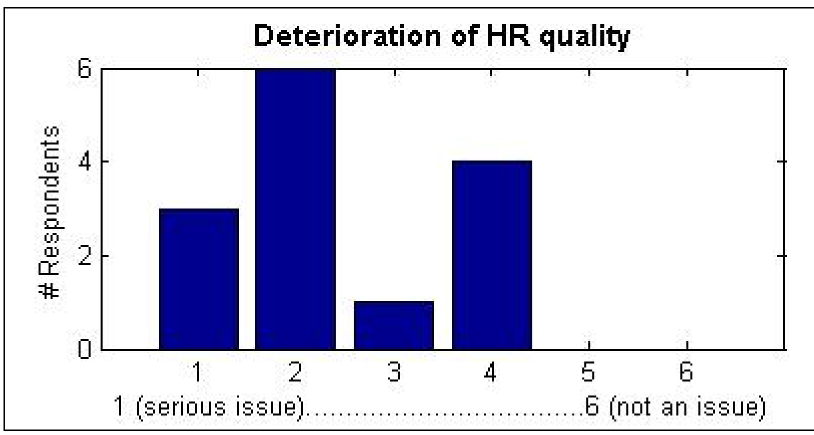



**Median: 2**
**Mean: 2.21**
**Mode: 1**
**Stdev: 1.26**

A fair level of consensus was achieved regarding this issue with a standard deviation of 1.26. The aggregated expert opinion is that the South African public sector's inability to retain and rejuvenate the human resources stock in the system will pose a hurdle to the system in the next 20 years. It must also be mentioned that six out of 14 respondents ranked this as a critical issue facing the system.

*2. Deterioration of quality of human resources working in R&D*

This question relates to a future threat to the level of quality of human resources working in the HES. This issue can be ascribed to multiple sources, including poor quality students entering the system as well as a lack of good remuneration and career opportunities, resulting in the level of quality of researchers in the system to deteriorate. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

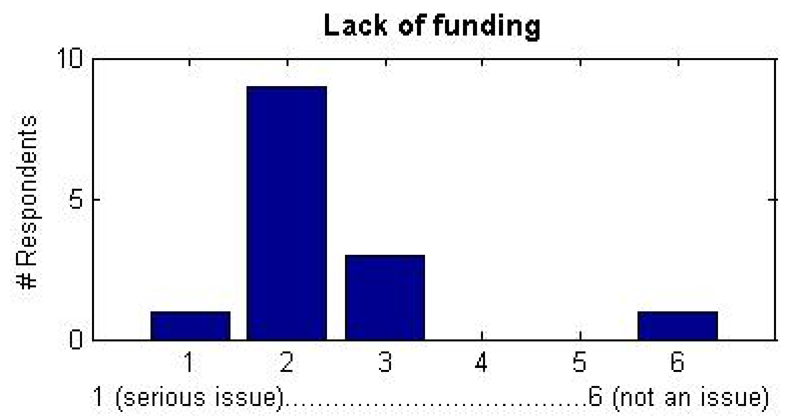



**Median: 2**
**Mean: 2.43**
**Mode: 2**
**Stdev: 1.12**

A reasonable level of consensus was achieved with a standard deviation of 1.12. A substantial amount of the respondents (>50%) rated this a critical or major issue (ranking 1 or 2) facing the public sector in the next 20 years. The experts' opinion gathered indicates that there is a deterioration of quality in human resources in the system, which could pose a threat to the R&D capacity in the public sector in the next 20 years.

*3. Lack of government funding to public sector to develop R&D and technology* *platforms*

This issue relates to a perceived issue that science councils have poor prospect for receiving sufficient government funding to sustain them fully. The rationale is that consultancy work should have a lower priority and should thus not be used to sustain research institutions. The hurdle foreseen for the next 20-year period is therefore that science councils might not receive adequate funding from government, which would, in turn, force these institutions to continue placing a high priority on work. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

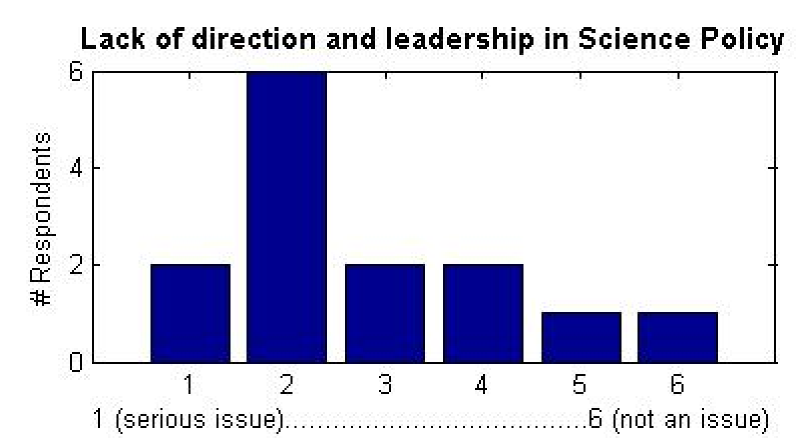



**Median: 2**
**Mean: 2.79**
**Mode: 2**
**Stdev: 1.42**

A reasonable level of consensus was achieved. Experts reached a reasonable level of consensus with a standard deviation of 1.13 regarding the existence of a major hurdle facing the HES regarding a lack of adequate government funding for R&D in the public sector.

*4. There is a lack of direction and leadership in science policy*

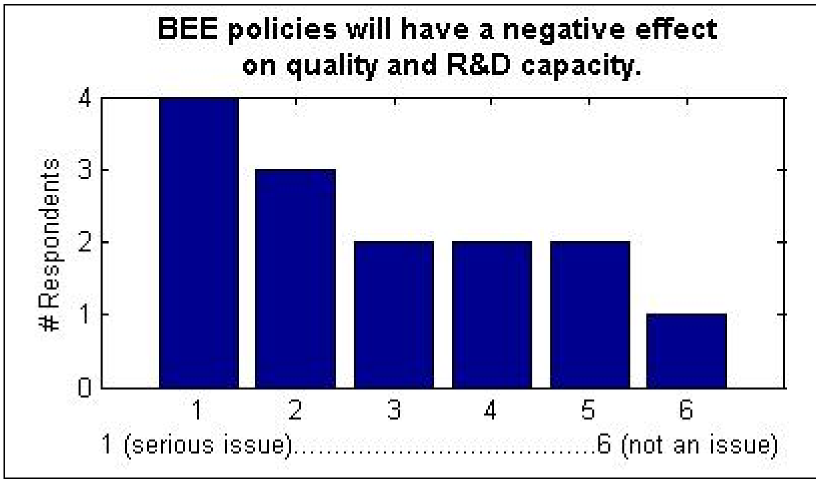
This perceived issue relates to a perception that, based on credible foresight, there is a lack of a coherent NIS, which could result in a continuous refocusing on the short term, i.e. 'flavour of the month' approach. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:




**Median: 2**
**Mean: 2.79**
**Mode: 2**
**Stdev: 1.42**

A fair level of consensus was achieved with a standard deviation of 1.42. An overall feeling that there is a lack of direction and leadership in science policy was recorded. A substantial amount of the respondents (>50%) rated this a critical or major issue (ranking 1 or 2) facing the public sector in the next 20 years. The median value ranking of this as a hurdle facing the public sector is 2.

*5. Current BEE policies will have a negative effect on quality and R&D capacity*
This issue relates to a perception that representativity receives too much attention and that racial quotas rather than competence are used as functional goals of policy instruments. This issued could ultimately impact negatively on the R&D system. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:




**Median: 2.5**
**Mean: 2.86**
**Mode: 1**
**Stdev: 1.64**

A low level of consensus was achieved with a standard deviation of 1.64. The respondents' feedback was inconclusive regarding the future effect of BEE policies on system performance. This is illustrated by the wide spectrum selection ranging from 1 to 6. It is however also evident that more than 50% of the experts do view this as a critical issue facing the public sector in years to come (9 respondents ranked this as an issue with criticality 1 to 3).

### 6.5.3 Feedback from the second round questionnaire (private sector)

#### 6.5.3.1 Round two: R&D output in the private sector
Respondent had the opportunity to revise their opinions of the applicability of using scientific output as a measure of R&D output in the private sector. The revised version of expert opinions (after the second round) is represented in the following graph:

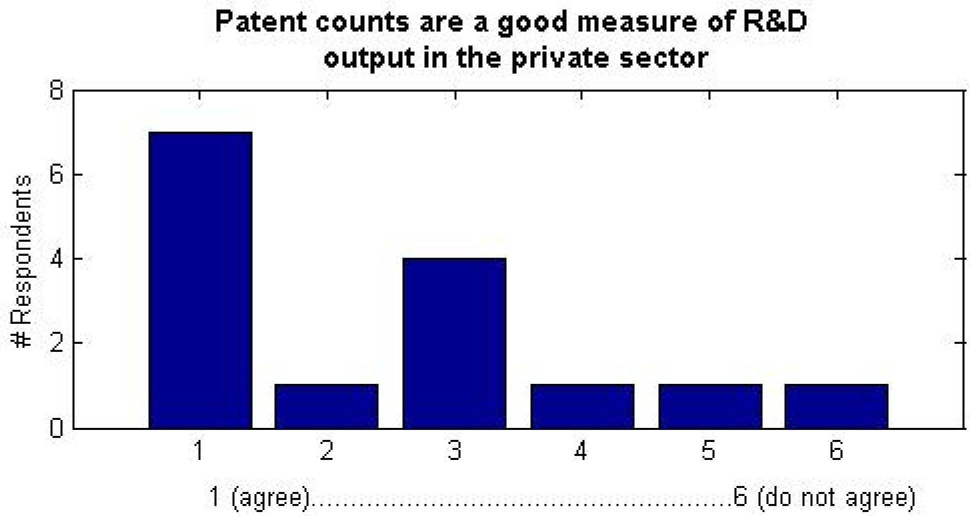



**Figure 6-6:** **Response Graph - Measurement of R&D in the Private Sector**

The comparison of movement of opinion and the group's level of agreement was analysed further. The following graph represents the movement of group opinion, measured in terms of the mean, and the level of consensus, measured in terms of the standard deviation, from round one to round two.

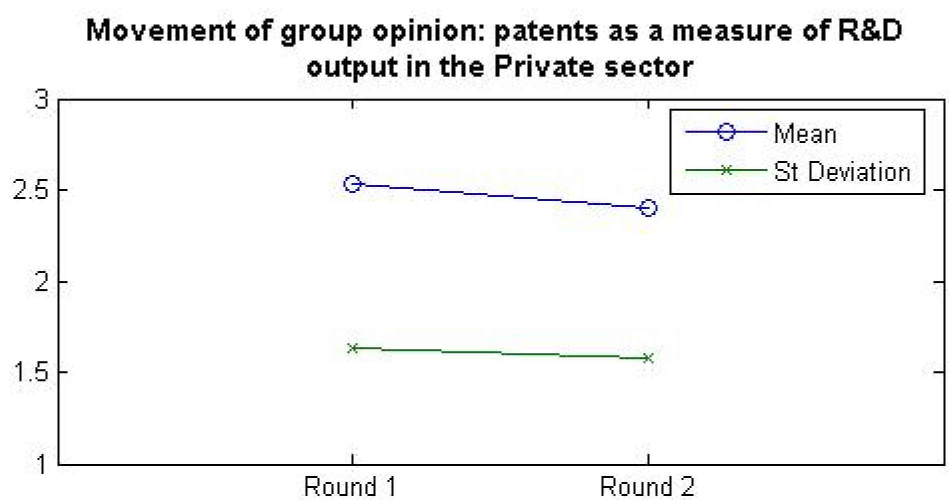



**Figure 6-7:** **Movement of Group Opinion - Patents to Measure R&D Output**

After the second round, a small improvement in the level of consensus was reached (standard deviation =1.63 to 1.58). In round one, the mean was 2.53, which decreased to 2.40 after round two.

The response graph (Figure 6-6) indicates that the mode is 1, with seven of the fourteen respondents agreeing (rank = 1) that the use of patent output is a good measure of R&D output in the private sector. From the 12 respondents, only three ranked above 3, which translates to an indication of a poor measure. We can therefore conclude that patent output is a relatively good measure of experimental development output in the South African private sector. This approach naturally also has its weaknesses, which is reflected in the mean rating of 2.40 by the expert panel.

#### 6.5.3.2 Round two: Hurdles faced in the private sector (next 20 years)

The following question was an open-ended question in the first round survey: **What are the general hurdles facing the South African private sector R&D system in the next 20 years?** A list of issues was compiled from the experts' responses in the first round.

The ideas generated in the first round questionnaire were categorised when developing the second round survey. In the second round survey, respondents were asked to rate issue categories on a scale from 1 to 6, where 1 indicates that it is a critical issue and a rating of 6 indicates that the issue does not exist.

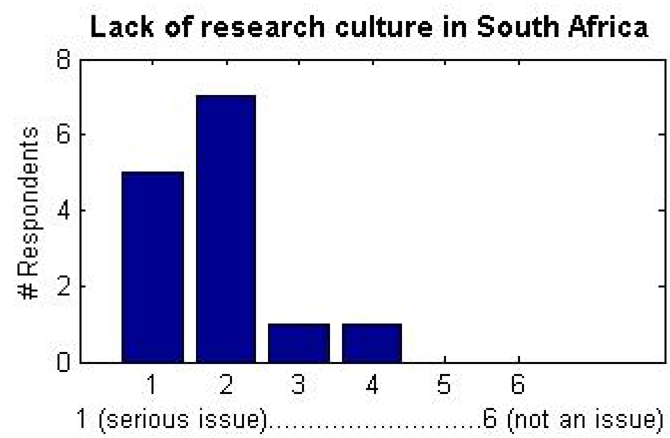
**Table 6-4: Summarised Issues Rankings for R&D in the Private Sector**

| Issue Category | Median | Mean | Mode | St.dev |
|---|---|---|---|---|
| 1. Lack of research culture in South Africa | 2 | 1.86 | 2 | 0.83 |
| 2. Lack of funding of R&D | 2 | 2.07 | 2 | 0.80 |
| 3. Restrictive communication infrastructure | 2 | 2.07 | 2 | 1.16 |
| 4. Inability to retain and rejuvenate the researchers stock in the system | 2 | 2.29 | 2 | 1.16 |
| 5. Current BEE policies having a negative effect on South Africa's future R&D capacity | 2.5 | 2.93 | 4 | 1.53 |
| 6. Poor linkages | 3 | 2.64 | 3 | 0.61 |
| 7. Lack of fiscal incentives from government to foster R&D culture in companies | 3 | 2.71 | 1 | 1.58 |
| 8. Deterioration of quality (skill level) of human resources working in R&D | 3 | 3.00 | 3 | 1.25 |
| 9. Lack of direction and leadership in science policy | 3.5 | 3.71 | 2 | 1.44 |

The issues listed in Table 6-4 are discussed in more detail in the following sections.

*1. Lack of research culture in SA*

Respondents were asked to rank this perceived hurdle facing the private sector in the next 20 years. This related to the perception that companies do not realise the importance and benefits of R&D to maintain competitiveness. In South Africa, the general mindset in the private sector is to import value added rather than to add the value through R&D. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

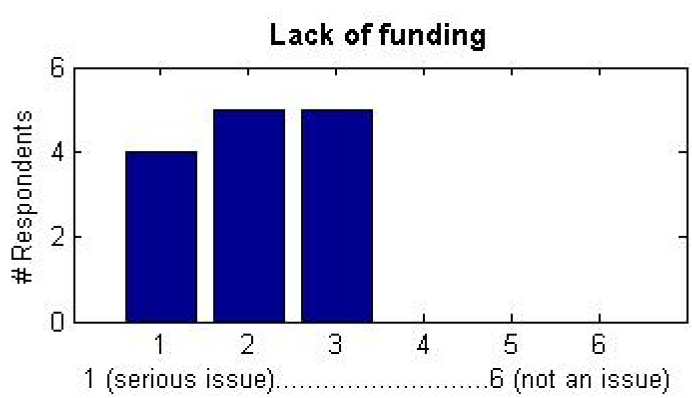



**Median: 2**
**Mean: 1.86**
**Mode: 2**
**Stdev: 0.83**

A high level of consensus was achieved regarding this issue, with a standard deviation of 0.83. A substantial amount of the respondents (>80%) rated this a critical issue or major issue (ranking 1 or 2) facing the private sector R&D system in the next 20 years.

*2. Lack of funding of R&D*

Respondents were asked to rank the criticality of the perceived issue that there is a lack of support for commercialisation of R&D and a lack of funding for local R&D. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

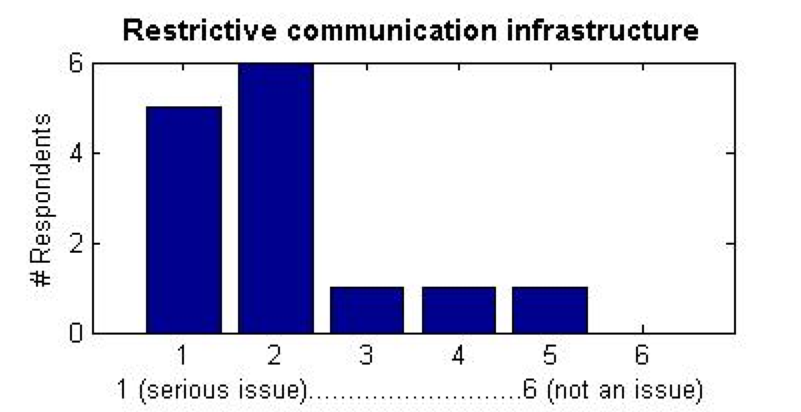



**Median: 2**
**Mean: 2.07**
**Mode: 2**
**Stdev: 0.80**

A high level of consensus was achieved regarding this issue, with a standard deviation of 0.80. All the respondents rated this as an issue (level 1 to 3). We can therefore conclude that a continued lack of funding for the R&D private sector seems to be a major hurdle facing the sector in the next 20 years.

*3. Restrictive communication infrastructure*

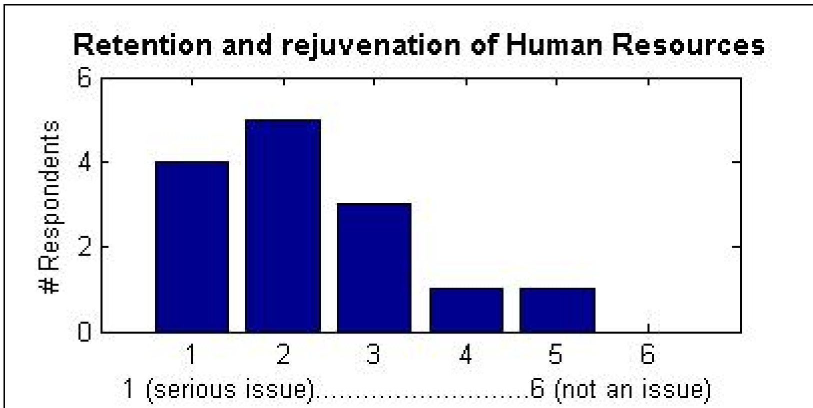
Respondents were asked to attach a level of criticality to the perceived issue that South Africa has a restrictive communication system. The following is a graph representation of the feedback received from the expert panel regarding the issue's level of criticality:




**Median: 2**
**Mean: 2.07**
**Mode: 2**
**Stdev: 1.16**

A reasonable level of consensus was achieved regarding this issue, with a standard deviation of 1.16. The majority of the respondent (11 out of 14) rated the issue as critical, thus level 1 and 2. We can therefore conclude that a restrictive communication seems to be a major hurdle facing the private sector R&D system in the next 20 years.

*4. Inability to retain and rejuvenate the researchers stock in the system*
This question relates to a perceived issue that the private sector faces poor prospects regarding the rejuvenation its human resources working in R&D due to issues such as: a low supply of skilled R&D personnel; an inadequate rewards system and the brain drain phenomenon. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

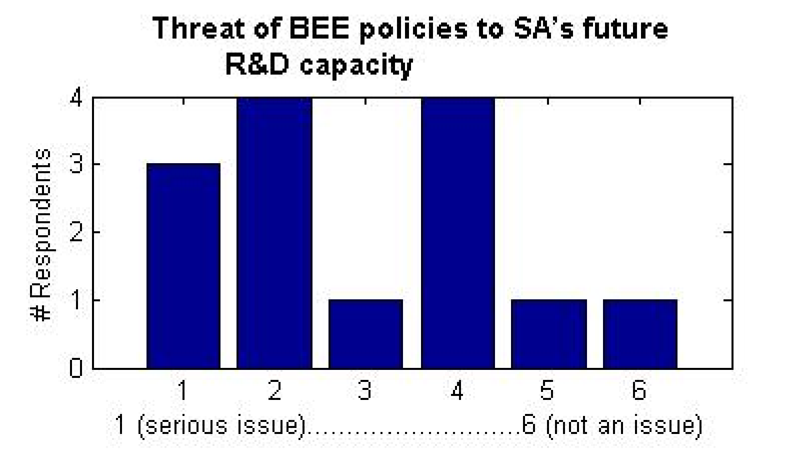



**Median: 2**
**Mean: 2.29**
**Mode: 2**
**Stdev: 1.16**

A fair level of consensus was achieved regarding this issue, with a standard deviation of 1.16. The majority of the respondent (12 out of 14) rated the issue as critical, thus level 1 to 3. We can therefore conclude that the experts foresee poor prospects for the private sector in terms of its ability to retain and rejuvenate its researchers stock during the next 20 years.

*5. Current BEE policies will have a negative effect on South Africa's future R&D capacity*
Respondents were asked to attach a level of criticality to the perceived issue that racial quotas rather than competence as functional goals of policy instruments could pose a

threat to the R&D capacity on the private sector. Other possible issues relating to this factor is that economic empowerment is sapping investment funds from company profits. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:

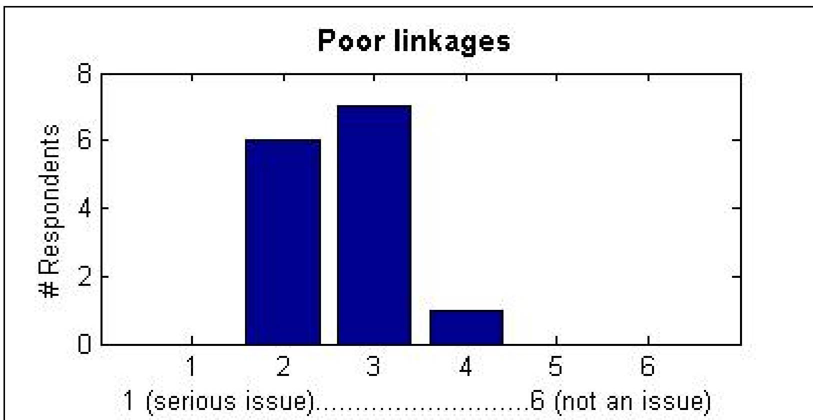



**Median: 2.5**
**Mean: 2.93**
**Mode: 4**
**Stdev: 1.53**

A low level of consensus was achieved regarding this issue with a standard deviation of 1.53. Although the mean value of the expert opinion rating (2.93) indicates that BEE policies should not pose a major hurdle to the private sector in the next 20 years, a substantial percentage of the respondents (7 out of 14) rated the issue as critical, thus a level 1 and 2. This indicates that a significant portion of the respondents views the issue to be a major concern regarding the sustainability of the R&D capacity in the sector.

*6. Poor linkages*

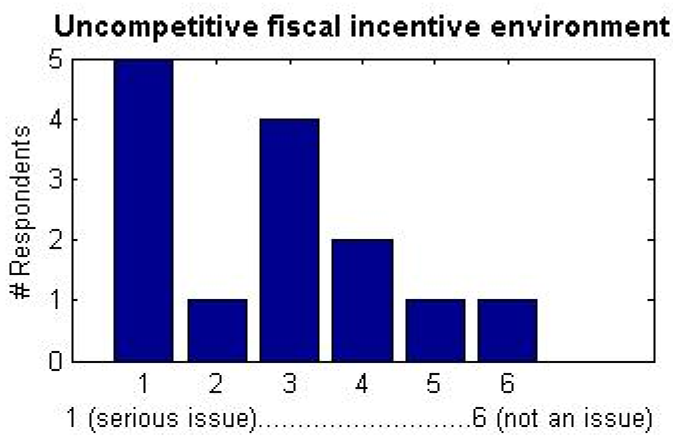
The private sector will not invest in R&D projects where the commercial potential is not obvious. Government thus needs to lead in strategic development projects to develop technology platforms from which the private sector can develop new products and processes. Respondents were asked to attach a level of criticality to the perceived issue that poor linkages exist between the private sector and government R&D programmes. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:




**Median: 3**
**Mean: 2.64**
**Mode: 3**
**Stdev: 0.61**

A high level of consensus was achieved regarding this issue, with a standard deviation of 0.61. The majority of the respondent (13 out of 14) rated the issue as critical, thus level 2 and 3. We can thus conclude that the expert panel acknowledges the issue that poor linkages exist. Respondents seem to agree that although this issue will continue to play a role in the next 20 years, it should not be viewed as a critical issue. Although this is thus not a critical issue, the experts agree that it could pose hurdles for the system in the next 20 years.

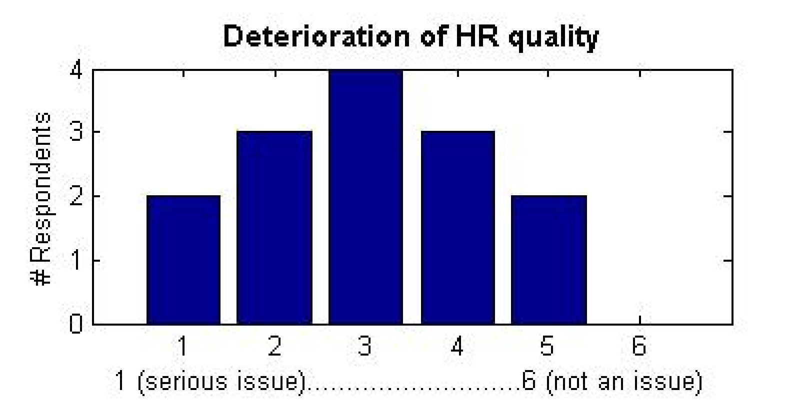
*7. Lack of fiscal incentives from government to foster R&D culture in companies*
Respondents were asked to attach a level of criticality to the perceived issue that there is a lack of tax incentives from government. Better tax breaks in other countries could result in a loss of R&D capacity as multinationals establish R&D centres where the fiscal environment is more advantageous. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:




**Median: 3**
**Mean: 2.71**
**Mode: 1**
**Stdev: 1.58**

A fairly low level of consensus was achieved regarding this issue, with a standard deviation of 1.58. The majority of the respondent (10 out of 14) rated the issue as critical, thus level 1 to 3. We can therefore conclude that the lack of an adequate fiscal incentive scheme could pose a hurdle for the private sector R&D system.

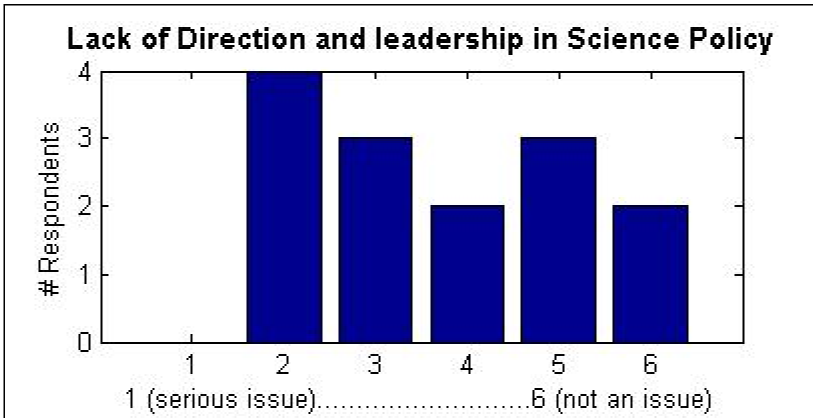
*8. Deterioration of quality (skill level) of human resources working in R&D*
This question relates to a future threat to the level of quality of human resources working in the private sector. Respondents were asked to comment on the level of criticality of the perceived issue that the quality of human resources working in R&D will deteriorate. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:




**Median: 3**
**Mean: 3.00**
**Mode: 3**
**Stdev: 1.25**

A fair level of consensus was reached with a standard deviation of 1.25. Respondents agree to some extent that a deterioration of quality and skill levels of human resources in the private sector might be seen as an area of concern (mean of 3).

*9. Lack of direction and leadership in science policy*
Respondents were asked to comment on the level of criticality of the perceived issue that there is a lack of a coherent science policy for the private sector. The following is a graphic representation of the feedback received from the expert panel regarding the issue's level of criticality:




**Median: 3.5**
**Mean: 3.71**
**Mode: 2**
**Stdev: 1.44**

A fair level of consensus was achieved with a standard deviation of 1.44. Respondents seem to agree that although this issue will continue to play a role in the next 20 years. The experts also agree that although this is not a critical issue, it must be viewed as an area of concern (mean 3.5).

## 6.6 Interpretation of Findings

In the past, the Delphi methodology suffered a high level of criticism. The fact that participants are not allowed to discuss the issues raised or to elaborate on the views provided has been accused of weakening the process (Walker & Selfe 1996, Goodman 1987). This issue also arises in the application of the Delphi methodology in this thesis.

In the first round, experts were asked to list hurdles facing South Africa's R&D system in the following 20 years. In the second round survey, the respondents were asked for their opinion on the seriousness of statements made regarding issues facing the South African R&D system.

The three main R&D sectors in South Africa's R&D system, namely the HES as well as the public and private sector, were treated separately. The following is a short summary of the issues and their levels of criticality as well as the level of consensus achieved in the Delphi study.

### 6.6.1 The HES

The following table summarises the aggregated respondents' opinion regarding the level of criticality of issues facing the R&D system in South Africa's HES over the next 20 years:

**Table 6-5: Summary Table of Hurdles Facing the HES in the Next 20 Years**

| Issue category | Median | Mean | Mode | St. Dev |
|---|---|---|---|---|
| **1.Inability to retain and rejuvenate human resources stock in the system** | 1.50 | 1.64 | 1.00 | 0.72 |
| **2. Lack of funding for R&D in the HES** | 2.00 | 2.29 | 2.00 | 1.10 |
| **3. Lack of female and black rresearchers for R&D to reach representative work force** | 2.00 | 2.71 | 2.00 | 1.48 |
| **4. Deterioration of quality of human resources working in R&D in the sector** | 2.50 | 2.43 | 1.00 | 1.12 |
| **5. Poor linkages posing a threat to future capacity and the relevance of R&D performed in the system** | 2.50 | 2.43 | 3.00 | 0.82 |
| **6. Lack of multidisciplinary research projects** | 3.00 | 3.29 | 2.00 | 1.53 |
| **7. Difficulty of successful R&D policy alignment with national priorities** | 3.00 | 3.29 | 3.00 | 0.96 |
| **8. Weak IP protection policies in HES** | 3.00 | 3.36 | 3.00 | 1.34 |
| **9. Inadequate funding of equipment** | 3.50 | 3.14 | 4.00 | 0.99 |

The level of consensus achieved by the group is measured by considering the standard deviation of opinion. It can be concluded that an overall reasonable level of agreement exists regarding the issues in the system.

An exception is the respondents' opinion on a future lack of female and black researchers in the HES (st. deviation is 1.48). This issue can therefore be identified as an area of further discussion and debate. Respondents also failed to agree (st. dev 1.53) on the criticality of the issues posed to the system during the next 20 years through a perceived lack of multidisciplinary research in the sector.

The discussion in Section 6.5.1.2 and the summary in Table 6-5 concluded that the most pressing issues facing the South African HES are:

- poor prospects for retaining and rejuvenating the human resources stock in the next 20 years
- poor prospect for adequate funding for R&D in the HES in the next 20 years
- a deterioration of quality of human resources in the system in the next 20 years; and
- a lack of female and black researchers for R&D to reach a representative work force.

These specific issues are also closely interlinked with the research questions posed in this thesis. However, this research question focuses on the effect of R&D expenditure on the development of an R&D capacity in the system. The scenarios consequently focuses mainly on answering questions regarding the effect of R&D expenditure on the future R&D capacity of the R&D system.

The following scenarios were developed to be tested on the system models. The objective was to tests the effect that some of these issues might have on the system in the next 20 years. To facilitate an answer to these questions, scenario tests were developed and tested on the system model regarding the hurdles foreseen by experts. Table 6-6 provides a short summary of the scenarios developed to be tested on the system model of R&D in the HES:

**Table 6-6: Scenarios Developed for the HES Model**

| |
|---|
| **Base Case:** Experts foresee a lack of adequate funding for R&D projects in the HES for R&D projects. How could a constant/unchanging investment in the South African HES affect its ability to produce R&D output and absorb knowledge? |
| **Scenario 1:** Experts foresee a lack of adequate funding for R&D projects in the HES for R&D projects. How could a decreasing level of investment in the South African HES affect its ability to produce R&D output and absorb knowledge? |
| **Scenario 2:** Experts foresee a deterioration of the quality of human resources in the system. How could the introduction of dedicated researchers in the system (science chairs) influence system performance in the development of centres of excellence? |
| **Scenario 3:** How could delayed reaction to the decay of R&D capacity influence the system and the cost to rebuild lost capacity? |
| **Scenario 4:** How could the introduction of better time management skills in academic and research personnel influence system performance? |

### 6.6.2 The Public sector

The following table summarises the aggregated respondent opinion regarding the level of criticality of issues facing the R&D system in South Africa's public sector R&D system over the next 20 years:

**Table 6-7: Summary Table of Hurdles Facing the Public Sector in the Next 20 Years**

| Issue category | Median | Mean | Mode | St. Dev |
|---|---|---|---|---|
| **1. Inability to retain and rejuvenate the researchers stock in the system** | 2 | 2.21 | 1 | 1.26 |
| **2. Lack of government funding to public sector to develop R&D and technology platforms** | 2 | 2.43 | 2 | 1.12 |
| **3. Deterioration of quality of human resources working in R&D** | 2 | 2.43 | 2 | 1.12 |
| **4. Lack of direction and leadership in science policy** | 2 | 2.79 | 2 | 1.42 |
| **5. Current BEE policies having negative effect on quality and R&D capacity** | 2.5 | 2.86 | 1 | 1.64 |

The level of consensus achieved by the group is measured by considering the standard deviation of opinion. It can be concluded that an overall reasonable level of agreement exists regarding the criticality of issues raised in the first round. The exception is the respondent opinion on the negative effect current BEE policies might have on quality and R&D capacity in the public sector (st. deviation is 1.64). This issue can therefore be identified as an area of further discussion and debate.

The discussion in Section 6.5.2.3 and the summary in Table 6-7 concluded that the most pressing issues facing the South African Public sector are:

- poor prospects for retaining and rejuvenating the human resources stock in the next 20 years
- poor prospect for adequate funding for R&D in the public sector in the next 20 years; and
- a deterioration of quality of human resources in the system in the next 20 years.

These specific issues are also closely interlinked with the research questions posed in this thesis. However, this research question focuses on the effect of R&D expenditure on the development of an R&D capacity in the system. The scenarios consequently focuses mainly on answering questions regarding the effect of R&D expenditure on the future R&D capacity of the R&D system.

To facilitate an answer to these questions, scenario tests were developed and tested on the system model regarding the hurdles foreseen by experts. Table 6-8 provides a short summary of the scenarios developed to be tested on the system model of R&D in the public sector:

**Table 6-8: Scenarios Developed for the Public Sector Model**

**Base Case:** Experts foresee a lack of adequate funding for R&D projects in the public sector. How could a constant/unchanging investment in the South African public sector R&D system affect its ability to produce R&D output and absorb knowledge?

**Scenario 1:** Experts foresee a lack of adequate funding for R&D projects in the public sector. How could a decreasing level of government investment in the South African public sector R&D system affect its ability to produce R&D output and absorb knowledge?

**Scenario 2:** Experts foresee a lack of adequate government funding for R&D projects in the public sector to enable it to attach less priority to consultancy work. How could moving away from the framework autonomy policy influence the system?

**Scenario 3:** How could an increasing/decreasing level of investment from government combined with a movement away from framework affect the system's ability to produce R&D output and absorb knowledge?

### 6.6.3 The Private sector

The following table summarises the aggregated respondents' opinion regarding the level of criticality of issues facing the R&D system in South Africa's private sector R&D system over the next 20 years:

**Table 6-9: Summary Table of Hurdles Facing the Private Sector in the Next 20 Years**

| | Median | Mean | Mode | Stdev |
|---|---|---|---|---|
| **1. Lack of research culture in South Africa** | 2 | 1.86 | 2 | 0.83 |
| **2. Lack of funding of R&D** | 2 | 2.07 | 2 | 0.80 |
| **3. Restrictive communication infrastructure** | 2 | 2.07 | 2 | 1.16 |
| **4. Inability to retain and rejuvenate the researchers stock in the system** | 2 | 2.29 | 2 | 1.16 |
| **5. Current BEE policies will have a negative effect on South Africa's future R&D capacity** | 2.5 | 2.93 | 4 | 1.53 |
| **6. Poor linkages** | 3 | 2.64 | 3 | 0.61 |
| **7. Lack of fiscal incentives from government to foster R&D culture in companies** | 3 | 2.71 | 1 | 1.58 |
| **8. Deterioration of quality (skill level) of human resources working in R&D** | 3 | 3.00 | 3 | 1.25 |
| **9. Lack of direction and leadership in science policy** | 3.5 | 3.71 | 2 | 1.44 |

The level of consensus achieved by the group is measured by considering the standard deviation of opinion. It can be concluded that an overall reasonable level of agreement exists regarding the criticality of issues raised in the first round.

The exception is the respondent opinion on the negative effect that current BEE policies might have on quality and R&D capacity in the private sector (st. deviation is 1.53). This issue can therefore be identified as an area of further discussion and debate.

Another issues that respondents failed to agree on was the level of criticality that an uncompetitive fiscal incentive environment will have on the private sector in the next 20 years.

The discussion in Section 6.5.2.3 and the summary in Table 6-9 concluded that some of the most pressing issues facing the South African Public sector R&D system are:

- a lack of a research culture poses a hurdle for the development of an R&D capacity in the next 20 years
- poor prospect for adequate funding for R&D in the public sector in the next 20 years
- a restrictive communication infrastructure; and
- poor prospects for retaining and rejuvenating the human resources stock in the next 20 years.

These specific issues are also closely interlinked with the research questions posed in this thesis. However, this research question focuses on the effect of R&D expenditure on the development of an R&D capacity in the system. The scenarios consequently focuses mainly on answering questions regarding the effect of R&D expenditure on the future R&D capacity of the R&D system.

The following scenarios were developed to be tested on the system models. The objective was to tests the effect that some of these issues might have on the system in the next 20 years. To facilitate an answer to these questions, scenario tests were developed and tested on the system model regarding the hurdles foreseen by experts. Table 6-6: provides a short summary of the scenarios developed to be tested on the system model of R&D in the private sector:

**Table 6-10: Scenarios Developed for the Private Sector Model**

**Base Case:** Experts foresee a lack of adequate funding for R&D projects in the private sector. How could a constant/unchanging investment in the South African private sector R&D system affect its ability to produce R&D output and absorb knowledge?

**Scenario 1:** Experts foresee a lack of adequate funding for R&D projects in the private sector. How could an increase/decreasing level of investment in the South African private sector R&D system affect its ability to produce R&D output and absorb knowledge?

**Scenario 2:** Experts rank a lack of an R&D culture as one of the biggest restrictions for the future development of the private sector's R&D capacity. Through fiscal incentives, a policy can be introduced to help foster an R&D culture in the private sector. This scenario was developed to find an answer to the following research question: How could the introduction of fiscal incentives influence R&D expenditure and the ability to produce R&D output and absorb knowledge?

**Scenario 3:** Experts rank a lack of an R&D culture as one of the biggest restrictions for the future development of the private sector's R&D capacity in the next 20 years. Scenario 3 examines and compares the model's predicted output for different levels of responsiveness from the private sector to tax incentive schemes in conjunction with varying delays of the private sector to react to these incentives

## 6.7 Conclusion

An analysis of the results section yields a conclusion that a reasonable overall level of agreement exists regarding the group opinion. The aggregated group opinion introduces two similar and repetitive themes regarding the most pressing issues in all three of the R&D sectors surveyed. These themes centre on issues regarding human resources working in R&D as well as the availability of funding.

A very low level of agreement (and consequently uncertainty) exists regarding the effect of BEE policies on the future capacity of the system. The issue presented the lowest level of consensus in all three sectors surveyed. This is therefore an issue that warrants further investigation.

In general, a sufficient level of consensus was achieved in the second round survey.

It must be remembered that the existence of a consensus does not necessarily mean that the correct answer, opinion or judgement has been identified. The real significance this study's outcome must be kept in mind, i.e. it assisted in identifying areas, in this case, hurdles faced by the South African R&D system, that the group of experts considered important.

# 7 HIGHER EDUCATION SECTOR MODEL

The conceptual model developed in Chapter 5 is applied to the South African HES. Although the author applied the same basic structure derived from theory, a number of changes important to the formulation of a model for R&D in the HES are made to the model structure. The quantification of the stocks and flows are however chosen to be descriptive of the sector's specific characteristics.

## 7.1 Overview of the Sector

According to the White Paper on S&T, the main objectives of the HES are to (DACST, 1996):

- generate new science related knowledge
- provide human resources
- create and sustain centres of excellence in the social and physical sciences and engineering; and
- participate in consortia and other joint research programmes.

South Africa's HES comprises 21 universities and 15 universities of technology (previously called technikons[1]). The previous government created separate higher education systems for the different cultural groups in the population. The 21 universities within the HES can be classified into 11 Historically Black Universities (HBU) and 10 Historically White Universities (HWU), also known as Historically Disadvantages Universities (HDU) and Historically Advantaged Universities (HAU) and respectively.

The current mergers between existing universities of technology and universities will ultimately result in a change in the HES landscape. Except for the incorporation of the Mamelodi Vista Campus into the University of Pretoria and Stellenbosch Dental School into the University of the Western Cape, four of the top universities, namely Cape Town, Stellenbosch, Pretoria and Witwatersrand, will be unaffected by the mergers. Despite the incorporation of its East London Campus into Fort Hare, the merger will also not effect Rhodes University.

For the purpose of this analysis, there are however some distinct differences between the two groups of universities. This is discussed in more detail in the following section.

### 7.1.1 R&D output in the HES

NACI (2004:69) presents statistics on the scientific output of university and technikons in terms of their SAPSE[2] research publications units for the years 1995, 1998 and 2001. The data yielded the following main trends (NACI, 2004:71):

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[1] In 1978, legislation was passed that ultimately led to the establishment of technikons. These institutions of higher learning were established along the lines of the British polytechnics. Initially, the staff hailed predominantly from a technical college background with an emphasis on skills training, which contributed greatly to the inhibition of an R&D culture (Marais, 2000).

[2] South African Post Secondary Education

- the overall HES showed a relatively constant count in SAPSE publications, i.e. 5 499 in 1995, with a slight decrease to 5 464 in 2001; and
- universities of technology (formerly known as technikons) showed an increase in contribution to the overall publications from 1.1% in 1995 to 2.8% in 2001. This however indicated that universities remained the largest contributors to South African publications.

Data gathered from the University of Pretoria institute for institutional research and planning (UP, 2005), indicated that the greatest part of scientific knowledge production still occurs in the HAUs. In fact, HAUs are responsible for an average of approximately 92% of scientific output (journals publications). It is evident that the HDUs are still responsible for only a very small contribution in terms of the generation of knowledge.

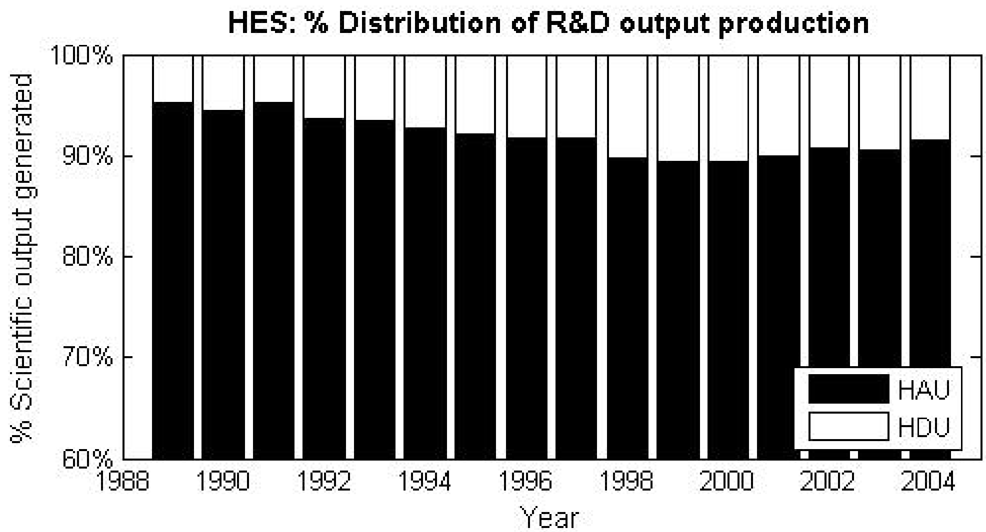



**Figure 7-1 Distribution of R&D output generation in the HES**

Scientific productivity, measured in scientific output per staff, yielded some interesting trends within the HES (NACI, (2004:69)):

- technikons showed very low productivity on an average of one publication for every 50 academic staff members, while the two most productive technikons produced one publication for every 12 academic staff members; and
- the difference in scientific productivity between the HDUs and HAUs is significant. In fact, HDUs produce no more than 0.2 articles per academic staff, whereas HAUs' average figure is close to 0.6.

### 7.1.2 Summary

Universities still contribute almost all the research performed in the HES. Although still a very small performer of R&D, technikons did show an increase in publications generated.

The above sections therefore concluded that HAUs are still the main players in the development of knowledge and creation of scientific output. The HDUs and universities of technology are responsible for a very small contribution to the creation of new knowledge in South Africa's HES. The role of technikons and HDUs is therefore ignored in the further development and application of the conceptual model of the creation of knowledge on the South African HES.

The following sections focus on the documentation and description of the data gathered for a systems dynamics model of R&D in the South African HES.

## 7.2 Data Gathering and Analysis

The actual data and data tables gathered is presented in Appendix B. The discussion of the data, the calibration and estimation of model parameters as well as conclusions drawn from data trends are discussed in this section.

### 7.2.1 R&D expenditure

The financial expenditure data was gathered from the South African R&D surveys. The R&D survey data was gathered for the survey years from 1977 to 2003. (See Appendix B for actual data and description of the survey methodology).

**Table 7-1: Data Gathered for R&D Expenditure in the HES**

| Data Input | Source | Table |
|---|---|---|
| Source funding from business sector to HES | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Source funding from public sector to HES | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Own funds HES (1980-2001) | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure (capital) in HES | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure (HR) in HES | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Expenditure on researchers<br>Expenditure on technicians<br>Expenditure on support staff | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on basic R&D in HES | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on applied R&D in HES | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on experimental development in HES | R&D survey (1981-2003) | **Error! Reference source not found.** |
| Investment in capital stock in HES | R&D survey (1981-2003) | **Error! Reference source not found.** |

Table 7-1 lists the data gathered of R&D expenditure in the HES from Frascati surveys from 1977 to 2003.

The Frascati data clearly indicates that a relatively small percentage of funding is directed towards capital resources as well as land and buildings. For the years 1977 to 2003, an average of approximately 4.85% (standard deviation 2.07%) of the total expenditure was directed towards capital. The percentage seems to be a relatively fixed ratio of the investment in R&D, at least for the conditions under which the system has been functioning. The data available also fails to provide in-dept detail in terms of the type of investment to different fields of science or the type of capital resources. Land and buildings are included in the investment data.

The percentage of R&D expenditure on labour in the HES seems relatively constant at approximately 50% of the total expenditure in the system. The percentage average for the years 1977 to 2003 is 49.8% (standard deviation of 7.51%). These figures therefore indicate that human resources have been one of the main sources of expenditures in R&D.

By far the greatest proportion of R&D investment is directed towards researchers, i.e. an average of 88.28% with standard deviation 6.52%, followed by technicians with 8.88% (standard deviation 5.76%), and lastly support personnel receiving only 2.84% (standard deviation 1.04%).

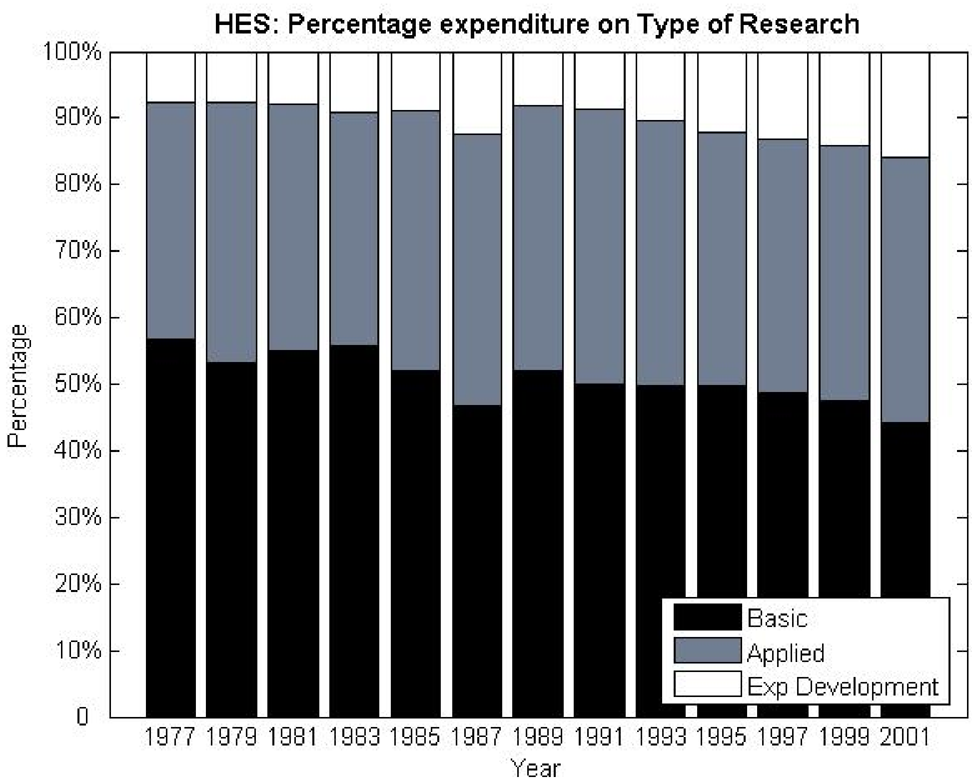



**Figure 7-2: Distribution of Expenditure on R&D**

The HES as a centre of the development of new knowledge is mainly directed towards basic research, which draws an average of 51.06% of R&D expenditure, followed by applied research with an average of 39% over the years 1979 to 2001. Experimental development constitutes an average of roughly 10% of the R&D expenditure. The data also yields Figure 7-2 evidence of a small but gradual shift towards experimental development over the 25-year period.

The following table summarises the analysis and discussion of R&D expenditure in the South African HES.

**Table 7-2: Conclusions from HES Expenditure Data Gathered**

| Parameter | Average for 1977 to 2001 | Standard Deviation |
|---|---|---|
| Percentage R&D expenditure (capital) in HES | 4.85% | 2.07% |
| Percentage R&D expenditure (human resources) in HES | 49.42% | 7.51% |
| Expenditure on researchers<br>Expenditure on technicians<br>Expenditure on support staff | 88.28%<br>8.00%<br>3.00% | 6.52%<br>5.76%<br>1.04% |
| Percentage expenditure on basic research<br>Percentage expenditure on applied research<br>Percentage expenditure on experimental development | 51.06%<br>38.45%<br>10.13% | 4.27%<br>2.01%<br>2.68% |

### 7.2.2 Human resources in the HES

The human resources data is gathered from both the South African R&D surveys as well as the HEMIS database. See Appendix B for the actual data and a description of the survey methodologies.

**Table 7-3: Data sources for HR in the HES**

| Data Input | Source | Table |
|---|---|---|
| Total human resources stock (1980-2001) | R&D Survey, HEMIS | **Error! Reference source not found.** |
| Fulltime equivalent researchers | R&D survey (1981-2001) | **Error! Reference source not found.** |

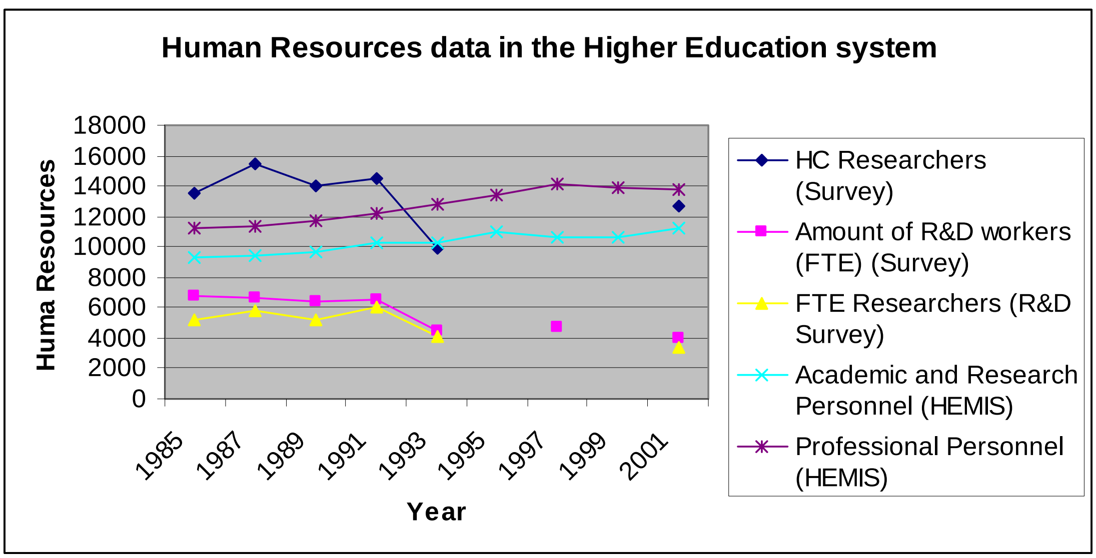



**Figure 7-3 Data gathered for Human Resources in the HES**

The changes in the methodology used in the R&D survey depicts a large decrease in terms of the headcount researchers from the recorded 1991 to 1993 survey data values. This change is however more likely attributed to an inconsistency in the definition of 'research personnel' in the HES R&D survey process rather than an actual change in the number of people in the system.

Totals of the headcount from the survey can therefore not be trusted in terms of the human resources employed in the system. Another measure is used instead. The *Academic and Research staff* field from the HEMIS database is used to measure the amount of people available for research duties in the South African HES. (see section **Error! Reference source not found.** for an account on the data gathering methodology followed for the HEMIS database).

However, to obtain a measure of the percentage of the time that academic and research staff on average spends on R&D, the author has no choice but to use the data as recorded in the R&D surveys.

The fulltime equivalent researchers in the system are recorded in the R&D Frascati surveys. The fulltime equivalent researchers employed is thus calculated from the surveyed researchers and the percentage time spent on R&D (see section **Error! Reference source not found.** for further details).

$$\%timeonR\&D = \frac{FTEstaff}{HCstaff} \qquad \textbf{7-1}$$

The following figure uses both the R&D survey data and data from the HEMIS database to reflect the percentage time that researchers spend on R&D.

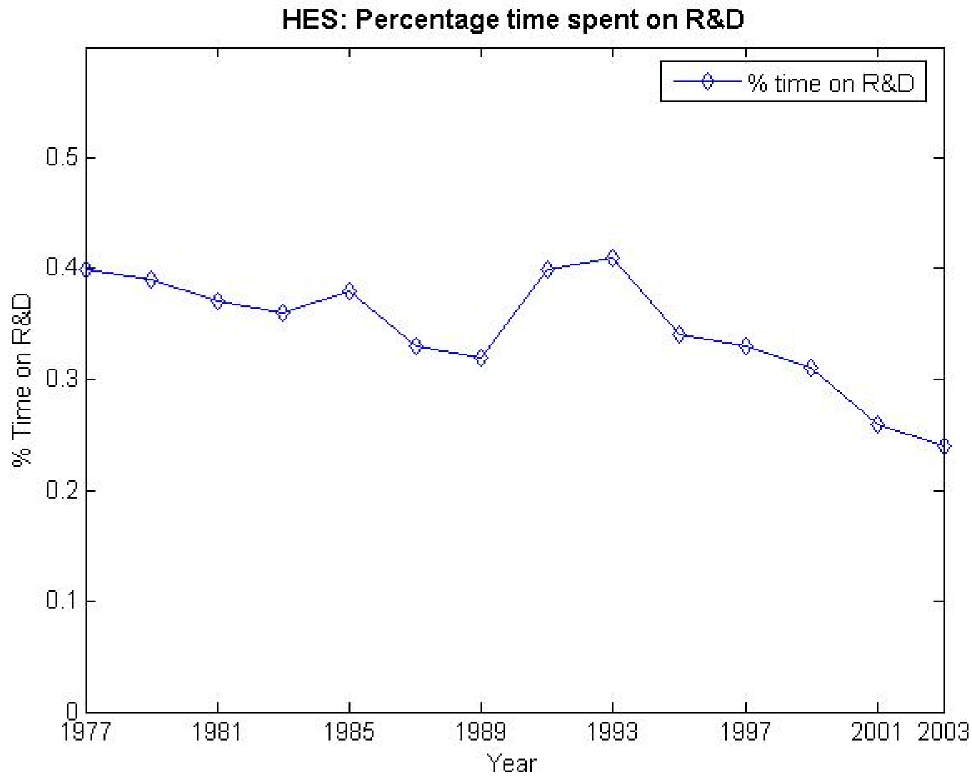



**Figure 7-4 Trend line of Percentage Time spent by Researchers in the System**

The HEMIS data and R&D survey data was used to construct a time series data set. A downward trend can be seen in the percentage time spent by researchers in the system. The figure therefore indicates that the percentage time that academic staff spent on R&D has decreased over the period 1977 to 2003.

### 7.2.3 The development of knowledge sub-system (HES)

The HES contributes mainly to the country's basic and applied research stock. The research expenditure in this sector is mainly on basic research, approximately 50% and applied research, approximately around 38%.

Data analysed from the South African Patent office indicate that a very small amount of patents are granted to South African universities. Patents are consequently not included as a measure for knowledge creation in the HES.

As the bulk of the scientific papers published by South Africans originate from the HES, the measure used for the creation of new knowledge is the amount of scientific journals that academics from these higher education institutions published in ISI journals (see Appendix A for a detailed explanation of the data gathering process conducted).

Although there are a number of well-known shortcomings in the approach of using scientific paper counts to measure scientific output, this is also a widely accepted measure[3]. The suitability of this approach was also evident from data gathered in the Delphi survey conducted in the research project. A panel of experts was asked regarding the applicability of using scientific publication output as an indicator of R&D output generated in the South Africa HES. Figure 7-5 is a graphical representation of the feedback from the expert panel.

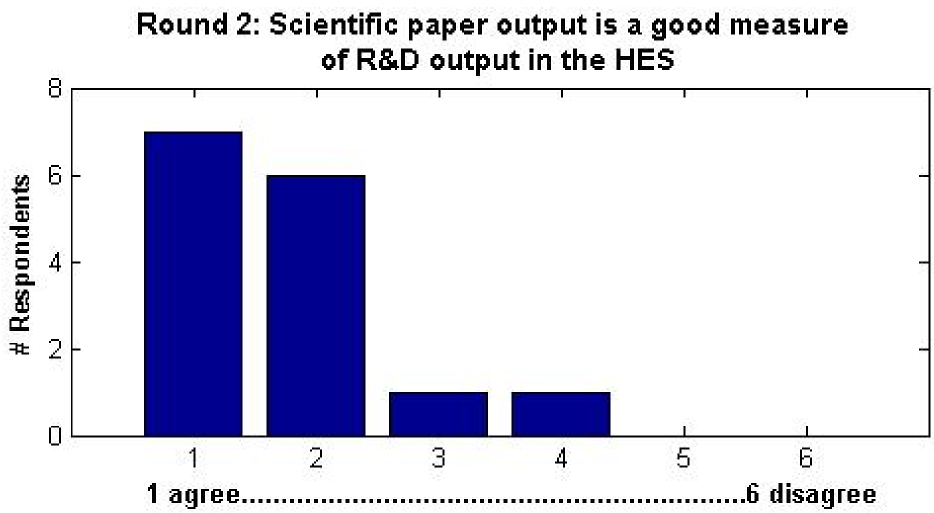



**Figure 7-5: Scientific Output as a Measure of R&D Output in the HES**

The expert panel therefore agrees that scientific publication output is an acceptable indicator to measure R&D output generated in the South African HES. The stock of knowledge created in the HES is consequently measured as a summation of the number of scientific papers published by authors in the sector (please see section **Error! Reference source not found.** for a detailed discussion on the findings regarding this issue in the Delphi study).

**Table 7-4: Data Gathering for the Knowledge Stocks in the HES**

| Data Input | Source | Table |
|---|---|---|
| Sector knowledge creation (Scientific Papers) (1980-2001) | ISI Web of Science, South African Patent Office | **Error! Reference source not found.** |
| Knowledge depreciation rate (citation curve) | ISI Web of Science (1981 - 2001) | **Error! Reference source not found.** |

[3] See Chapter 2 for a discussion on the use of bibliometrics and the shortcomings in this approach

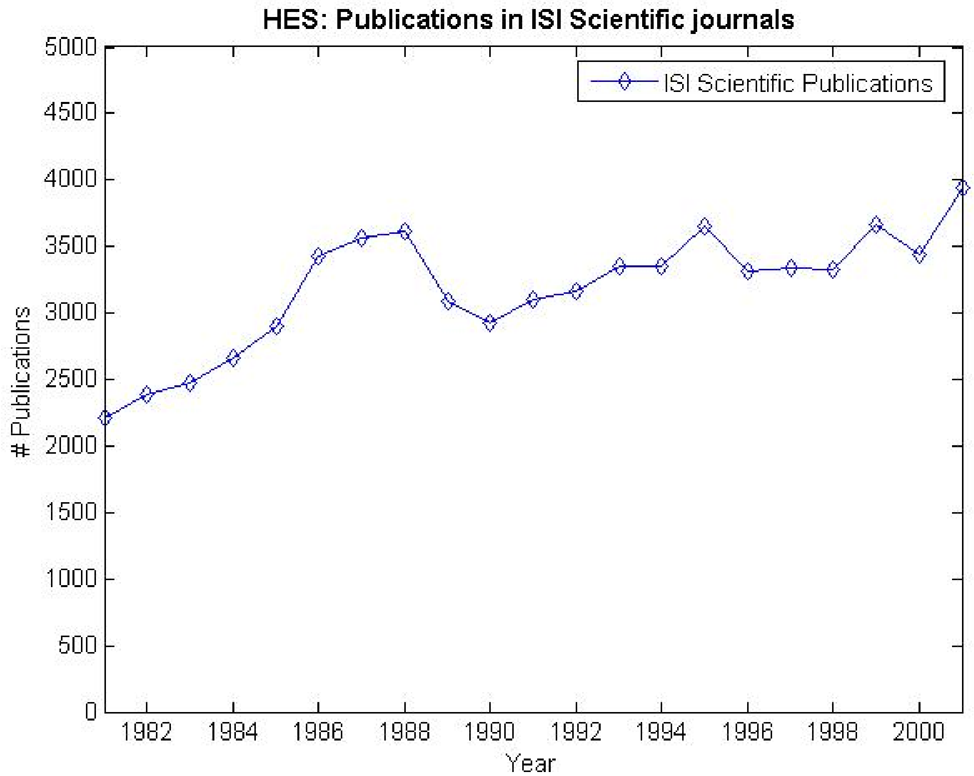



**Figure 7-6 Scientific Papers generated in the South African HES**

The following figure is a graphical representation of data showing that since 1988, South Africa started to slip in it's international position as a knowledge creator.

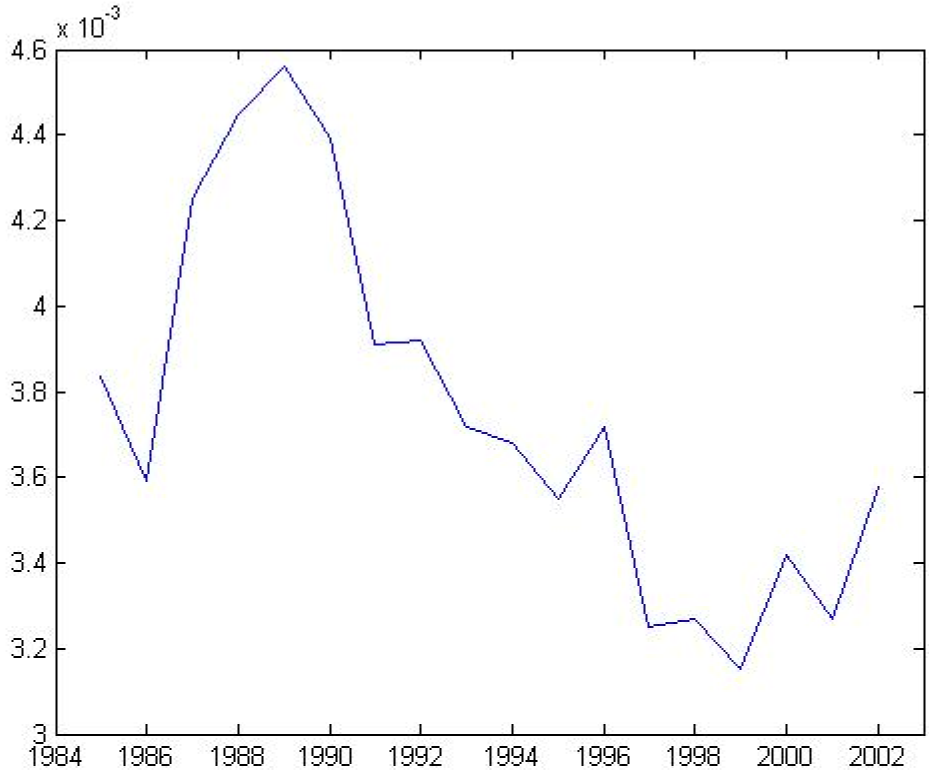



**Figure 7-7: South Africa's share of world output in terms of ISI publications**

Scientific publications is also used to gauge the absorptive capacity of the HES. To find an indicator of this rate, the rate at which other South African authors access scientific knowledge papers and at which it is made part of the South African knowledge stock must be found.

### 7.2.4 Absorption of knowledge sub-system

**Table 7-5: Data Gathering for the Absorbed Knowledge Stocks**

| Data Input | Source | Table |
|---|---|---|
| Rate of knowledge absorption (references) | ISI Web of Science | **Error! Reference source not found.** |
| Initialisation of absorbed knowledge stock in 1980 | Estimated | |

Since papers are used as a measure of the development of new knowledge in the sector, the absorption of knowledge is also measured through the rate at which the scientists read, interpret and use knowledge created in the external environment to produce new knowledge. The reference rate (references made from South African articles to existing knowledge) is used as a measure of the absorption of knowledge into the system.

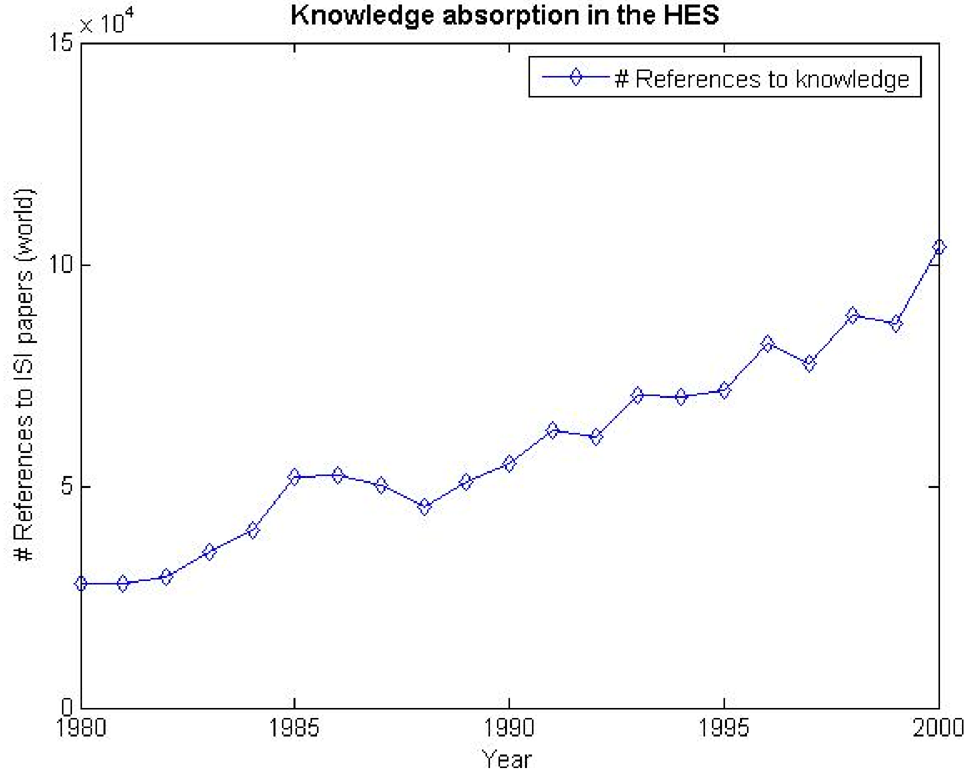


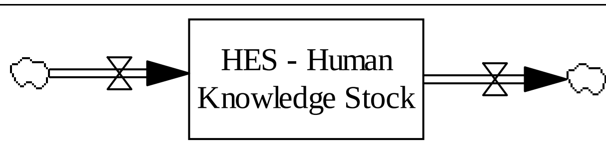

**Figure 7-8.Number of references made to knowledge created in an external environment.**

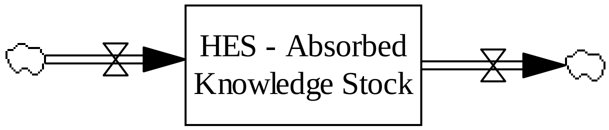
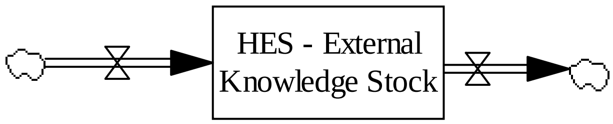
Figure 7-8 is a graphical representation of the data gathered that will be used as the rate at which the system absorbs new knowledge.

## 7.3 Quantification of Stocks in the HES

From the discussion above, the following table describes the unit of measurement and quantification of stocks in the model:

**Table 7-6: Stock for the HES Model**

| Stock | Quantification |
|---|---|
|   | Head count researchers employed during the year<br>Unit: Researcher |
|   | Cumulative years R&D experience of researchers<br>Unit: Year |

| Stock | Quantification |
|---|---|
|   | R&D output generated in the HES<br>Unit: Papers |
|   | Stock of absorbed knowledge is measured by counting the amount of foreign papers cited by scientists in the system<br>Unit: Papers |
|   | The stock of external knowledge is the amount of scientific publications created in the external environment<br>Unit: Papers |

At this point, the data gathering phase has been completed and the decisions in the quantification of the stocks in the conceptual model made. The following section describes the process of applying the data to the conceptual model.

## 7.4 Developing the Model

### See Appendix F for the stock and flow diagram for the HES model

This section describes the actual population of the conceptual model with the data gathered. The first subsystem developed is the human resources subsystem.

**Table 7-7: Parameters for Estimation in the HES Model**

| Parameter | Estimated value |
|---|---|
| Average retirement age | 65 years |
| Recruitment distribution between cohorts<br>• Young<br>• Experienced<br>• Mature | <br>77%<br>11%<br>11% |
| Natural attrition percentage of cohorts<br>• Young<br>• Experienced<br>• Mature | <br>5%<br>5%<br>5% |
| Initial for the HR stocks (1980)<br>• Young<br>• Experienced<br>• Mature | <br>4120<br>2480<br>1650 |
| Decay rate of knowledge stocks and experience | 8-10 % per year |

The recruitment distribution between cohorts was estimated. Output generated from the human resources sector indicates a close resemblance with the current ageing-trend observed in the HES.

Figure 7-9 is a graphical representation of a comparison between the model output and the actual data gathered from the HEMIS database.

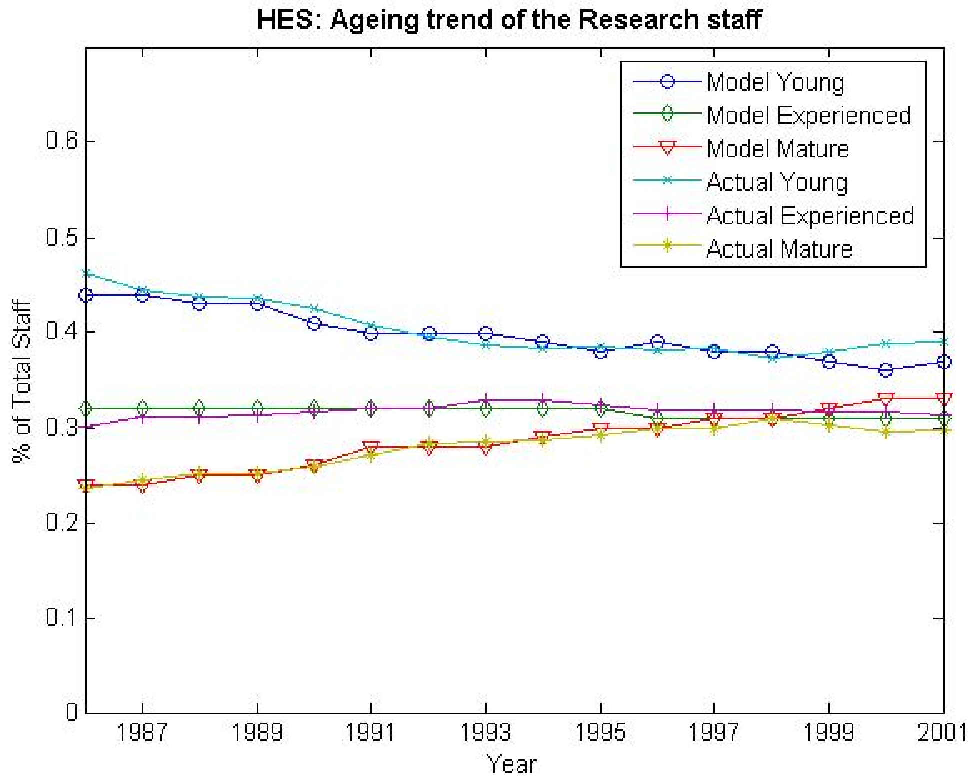



**Figure 7-9: Model output recreating trend of the ageing of Scientific workforce.**

The above figure depicts the percentage of the total stock comprising the young, experienced and mature researcher stocks. The figure indicates that the young researcher stock, i.e. researchers between the ages of 25 and 40, decreased from approximately 46% in 1986 to approximately 36% in 2001. The mature researchers stock, i.e. academic and research staff aged 50 and older, has increased from approximately 22% in 1986 to approximately 30% of the total academic and research staff employed in the South African university sector.

The foremost aspects of the ageing trends seen in the HEMIS data are recreated in the model's human resources subsystem. In general the age of the academic and research workforce seems to have increased. Many researchers have observed and documented this trend. It has also been mentioned in government policy reports as an area of concern (NACI, 2002), (DACST, July 2002).

*The FTE research staff in HES*

It is hypothesised that as the student-to-staff ratio increases, staff members will have to cope with a higher lecturing and administrative workload, i.e. more lectures, more exam papers to mark and in general, more administration.

A regression is consequently performed to model the effect that the student-staff relationship has on the system's ability to perform R&D, thus the average time spent on R&D. A regression analysis of the effect that an increase in the student-staff ratio might have on the percentage time that staff can spend on R&D yields the following result:

**Table 7-8:** **SAS Output – HES HR Percentage Time spent on R&D**

The REG Procedure
Model: MODEL1
Dependent Variable: Percentage

Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 1 | 0.02221 | 0.02221 | 46.98 | 0.0001 |
| Error | 8 | 0.00378 | 0.00047279 | | |
| Corrected Total | 9 | 0.02599 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 0.02174 | R-Square | 0.8545 |
| Dependent Mean | 0.33618 | Adj R-Sq | 0.8363 |
| Coeff Var | 6.46789 | | |

Parameter Estimates

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | 0.58592 | 0.03708 | 15.80 | <.0001 |
| studentstaff | 1 | -0.16677 | 0.02433 | -6.85 | 0.0001 |

The REG Procedure
Model: MODEL1

Dependent Variable: Percentage

Test of First and Second
Moment Specification

| DF | Chi-Square | Pr > ChiSq |
|---|---|---|
| 2 | 1.57 | 0.4554 |

The hypothesis is supported through the data. From the F statistic can be concluded that the result is highly significant (F=46.98, p<0.0001), indicating that the model explains a significant portion of the variation in the data. The R-square statistics state that the model accounts for 85% of the variation of the percentage time spent by staff on R&D activities.

The Durbin Watson statistic indicates that the model has no autocorrelation.

White's test for heteroscedasticity yields that we cannot reject the null hypothesis that the errors are homoscedastic. Therefore, no heteroscedasticity seems to be present in the error terms.

Data for the student-to-staff ratio is available from the HEMIS database on an annual basis (18 data points). The author did however encounter the problem that data from the R&D surveys are only gathered biannually and data points are therefore only available for every second year (10 data points). Although the regression analysis results indicate that the variable used in the regression is highly significant, the lack of enough data points leads to a problem where not enough data points are available for the rigorous testing for non-spuriousness of the modelled relationship. Although the stationarity tests were conducted on the model successfully, the amount of data points is insufficient to ensure the test's reliability. The outcome can thus not be used as a definite test for the non-spuriousness of the relationship. (See section **Error! Reference source not found.** for a detailed discussion on the statistical tests conducted on the model)

As this model is intended as an explorative study used for what-if scenario testing, we still choose to make use of the relationship. It is however important to keep in mind that the statistical relationship and the non-spuriousness of the model could to date not be proven rigorously.

The fitted equation for this model is:

$$\%TimeSpentonR\,\&\,D = 0.58592 + (-0.16677) * \frac{StudentStaff\ \mathrm{Re}\,lationship}{StudentStaff\ \mathrm{Re}\,lationship^{*}} \qquad \textbf{7-2}$$

**Where** $StudentStaff\ \mathrm{Re}\,lationship^{*} = 26.15$

The following is a graphical representation of the relationship as derived from the regression analysis.

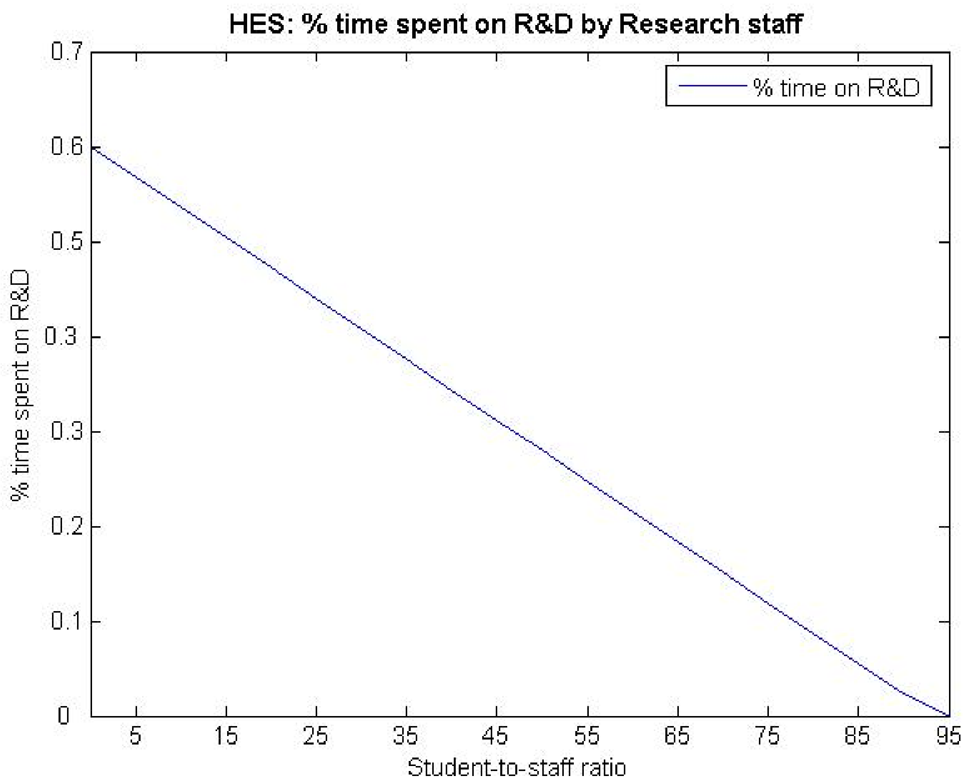



**Figure 7-10: Relationship between Student-to-Staff ratio and Time Spent on R&D.**

As the result of the regression analysis equation has to be expressed as a percentage, the equation, which is used as an input to the model, is modified to ensure that a negative value for the percentage time on research is not obtained. As the straight-line fit goes through 0, it is thus not allowed to become negative but forced to remain zero.

The fulltime equivalent researchers can therefore now be computed by multiplying the average percentage time that academic and research staff spends on R&D by the number of academic and research staff employed in the system.

$$FTE(i) = S_{HR}(i) \times \%TimeSpentonR\,\&\,D \qquad \textbf{7-3}$$

### 7.4.1 Experience stock

The experience stock uses the co-flow structure as discussed in the development of the conceptual model diagram in Chapter 4. The experience gained from conducting research is a cumulative function of the FTE researchers working in the system during a specific period of time.

A first experiment tests the model behaviour of the development of experience in R&D. All experience stocks are initialised with zero values. The target academic and research staff in the system is set to be a constant value of 8 500. The average percentage time spent by researchers on R&D is set to be a constant 35%.

An examination of the average level of experience possessed by the different age cohorts of academic and research staff as the system reaches equilibrium yields an interesting observation. Figure 7-11 depicts the output from the model for the simulation run for a constant average of 35% time spent on R&D.

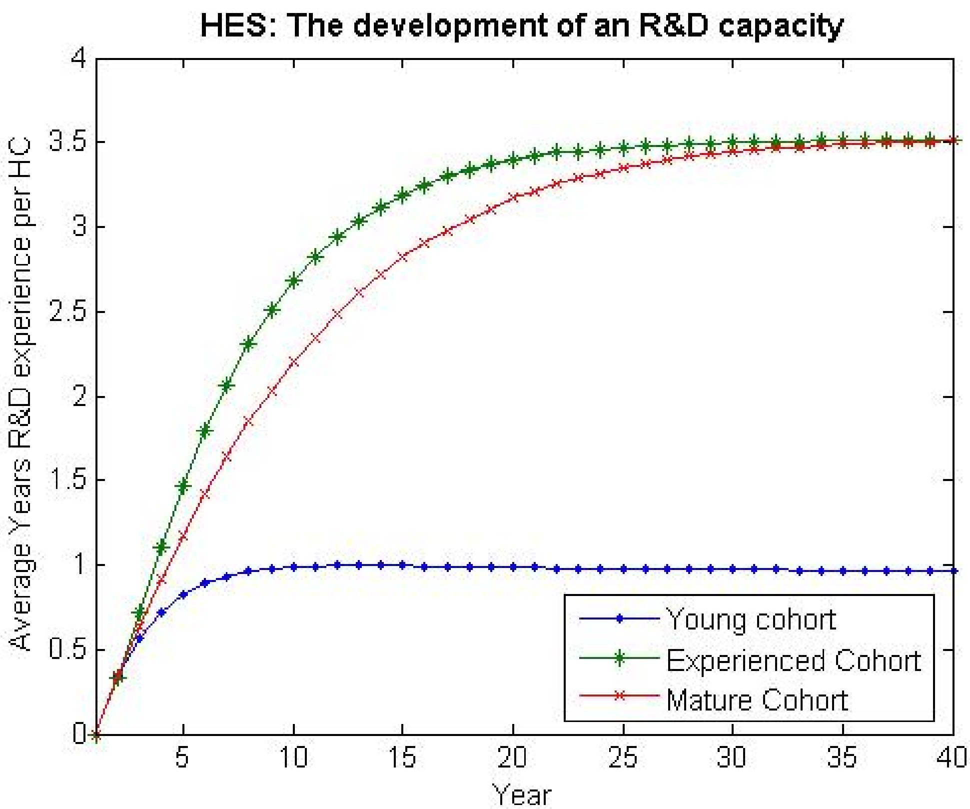



**Figure 7-11 The Development of an R&D Capacity (Age Cohorts)**

Figure 7-11 reflects the expected trend that young researchers on average will not possess the same capabilities and tacit knowledge as older, more experienced researchers. The equilibrium levels of experience per person approaches the same value for both the experienced and mature researcher stocks. This phenomenon can be explained by the dynamic included in the model that knowledge also decays through 'forgetting' and that for a fixed R&D intensity, the system approaches an equilibrium level where only knowledge gained within a given amount of years remains in the system.

The conclusion can therefore be drawn that the system reaches a state of equilibrium after a number of years. It is assumed that these equilibrium values are close enough approximations of the average starting value for experience per person in the cohorts. By using the equilibrium levels, we find values for the experience stocks' initial values.

**Figure 7-12: Initial Values for the Experience Stocks**

| Stock Name | Initial Value |
|---|---|
| Young exp stock (25-39) | 3709 (years) – 4120 with 1.1 yrs |
| Experienced exp stock (40-49) | 57288 (years) – 2480 with 3.3 yrs |
| Mature exp stock (50+) | 43560 (years) – 1650 with 3.3 yrs |

### 7.4.2 Parameter assessment

Parameters are assessed statistically using regression analysis. Two rates are modelled by using the stocks built up in the system.

#### 7.4.2.1 Development rate of knowledge

Through regression analysis, the following model is developed for the production of new knowledge output. It is calculated from the contributions made from different stocks in the system. The following expression is formulated for the R&D output productivity per FTE researcher working in the system:

- $R_{Paper} / S_{FTE}$ : R&D output rate per FTE researcher person on the system
- $S_{Experience} / S_{HC}$ : Average Experience Stock per researcher in the system; and
- $S_{Absorbed} / S_{HC}$ : Average Absorbed knowledge per researcher in the system.

A multiplicative model is developed for the development rate of papers per fulltime person working in the system:

$$\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}} = c * \left(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}\right)^a * \left(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}\right)^b \qquad \textbf{7-4}$$

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}}\right) = \ln(c) + a * \ln\left(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}\right) + b * \ln\left(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}\right)$$

**7-5**

The expression used to perform the regression for estimating the parameters $a$, $b$ and $c$ will therefore be as follows:

**Table 7-9:** **SAS Code – Development of Knowledge**

```
                      Maximum Likelihood Estimates

     SSE                  0.08224994    DFE                      18
     MSE                     0.00457    Root MSE            0.06760
     SBC                  -47.714313    AIC              -52.078483
     Regress R-Square         0.8178    Total R-Square       0.9334
     Durbin-Watson            1.8688    Pr < DW              0.2427
     Pr > DW                  0.7573
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and
      Pr>DW is the p-value for testing negative autocorrelation.


                                      Standard                 Approx
  Variable        DF      Estimate       Error    t Value    Pr > |t|

  Intercept        1     -0.004500      0.0807      -0.06      0.9562
  absperhc         1        0.6998      0.1220       5.73      <.0001
  expperhc         1        1.5280      0.4756       3.21      0.0048
  AR1              1       -0.6004      0.1938      -3.10      0.0062


                Autoregressive parameters assumed given.

                                      Standard                 Approx
  Variable        DF      Estimate       Error    t Value    Pr > |t|
```

```
Intercept         1     -0.004500       0.0797      -0.06       0.9556
absperhc          1        0.6998       0.1186       5.90       <.0001
expperhc          1        1.5280       0.4756       3.21       0.0048
```

The following section is a summary of the statistical analysis conducted to estimate model parameters. See section **Error! Reference source not found.** for a detailed account of the statistical analysis).

The **Total** Regress R-Square 0.8178 statistic indicates that the model accounts for 81.78% of the variation of the percentage time spent by staff on R&D activities. Both variables included in the model (absperhc and expperhc) are highly significant.

As the first model fitted with zero lag proves to have autocorrelation, an autoregressive model is fitted with lag = 1. The Durban Watson test statistic was used to gauge for autocorrelation. This statistic is 1.8688 with (Pr < DW = 0.2427 > 0.05 and (Pr < DW = 0.7573) < 0.95, which indicates that the model does not have autocorrelation.

Colinearity tests were conducted on the data. All the condition indexes from the regression model are much smaller than 30. We can therefore conclude that no colinearity is present.

The test conduced for heteroscedasticity indicated that the model error terms are homoscedastic.

The Phillips-Perron test was used to test stationarity and indicated that all variables included in the model are non-stationary. After fitting the model, it was tested for stationarity. The test proved that the model residual is stationary and the variables are cointegrated. This implies that the regression is not spurious.

The parameters have thus been estimated successfully for the following expression.

$$\ln\left(\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}}\right) = \ln(c) + a * \ln\left(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}\right) + b * \ln\left(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}\right)$$

**7-6**

The following table summarises the variable values as well as the variance introduced into the parameter in the model. The variance of the parameters is set equal to the standard error as reported in the SAS output.

**Table 7-10: Summary of the Estimated Parameters for the Development of Knowledge**

| Parameter | Estimate | Variance (s.e.) |
|---|---|---|
| Intercept (c) | -0.00443 | 0.0797 |
| Absperhc (a) | 0.6998 | 0.1186 |
| Expperhc (b) | 1.5280 | 0.4756 |

These parameters with the variance values were used in the model, which yields the following output for the development of scientific output (measured in terms of scientific papers).

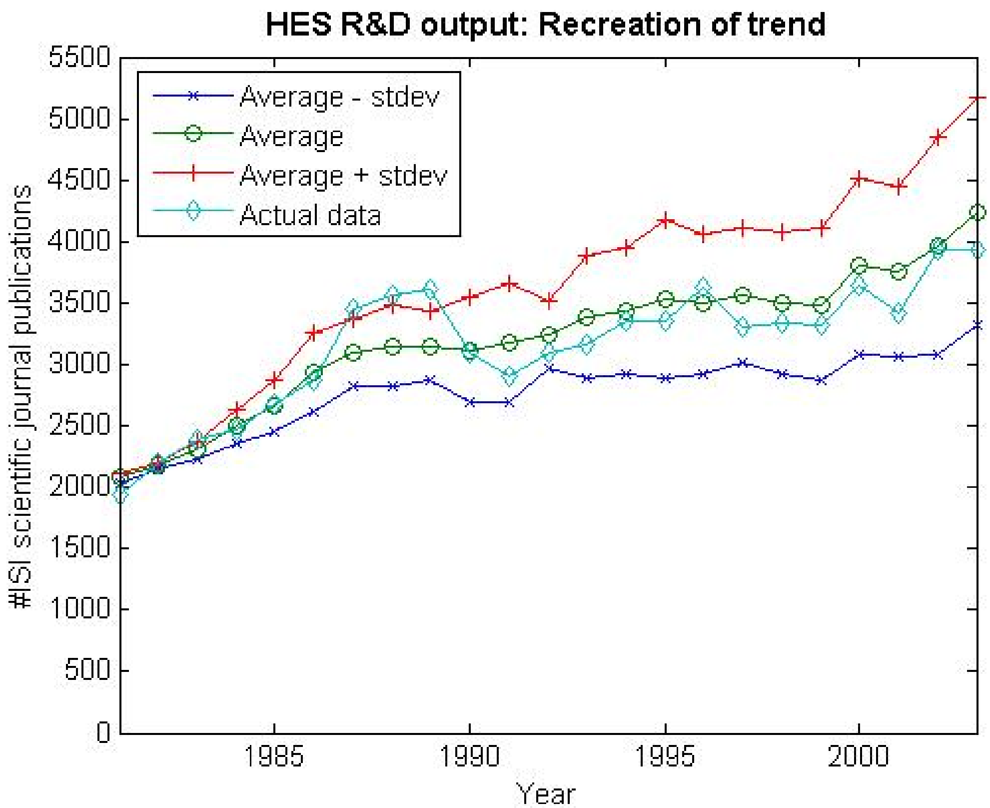



**Figure 7-13: Model Recreation of the Production of Scientific Output**

The coefficient of the determination ($R^2$), i.e. the fraction of the variance in the data explained by the model is computed to be 0.85087, which indicates that the computed average of the model runs contains approximately 85% of the variation in the actual data.

Recalling the development of the conceptual model, it was hypothesised that the creation of knowledge can only exist in the presence of the absorption of knowledge. The following section consequently deals with the development of a model for the absorption of knowledge subsystem in the model.

### 7.4.2.2 Absorption of knowledge

Through regression analysis, the following model is developed for the absorption of knowledge from the external environment. It is computed from the contributions made from different stocks in the system. The following expression is formulated for the R&D knowledge absorption rate in the system:

- $R_{Absorptionr}$ : Absorption rate of knowledge in the system
- $S_{R\&Doutput} * S_{FTE}$ : R&D output stock interacting with the presence of people fulltime equivalent people who can draw on the stocks of knowledge person in system; and

- $S_{World} / S_{HC}$ : Available external knowledge stock per headcount personnel employed in the system.

A multiplicative model is developed for the absorption rate per fulltime person working in the system:

$$\frac{R_{Absorptionr}}{R^*_{Absorption}} = f * (\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}})^d * (\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}})^e \qquad \textbf{7-7}$$

This expression is linearised by taking the log-linear form:

$$\ln(\frac{R_{Absorptionr}}{R^*_{Absorption}}) = f + d * \ln(\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}}) + e * \ln(\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}}) \qquad \textbf{7-8}$$

The expression used to perform the regression for estimating the parameters $d$, $e$ and $f$ is thus as follows:

**Table 7-11: SAS Output for the Estimation of Model Parameters**

```
                       Maximum Likelihood Estimates

    SSE                   0.18500614    DFE                        18
    MSE                      0.01028    Root MSE              0.10138
    SBC                   -29.491802    AIC                -33.855972
    Regress R-Square          0.6812    Total R-Square         0.9458
    Durbin-Watson             2.0372    Pr < DW                0.4148
    Pr > DW                   0.5852
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and
      Pr>DW is the p-value for testing negative autocorrelation.

                                             Standard                 Approx
  Variable         DF      Estimate         Error     t Value    Pr > |t|

  Intercept         1       -0.0443        0.1432       -0.31      0.7606
  RDFTE             1        0.6165        0.2642        2.33      0.0314
  wsperhc           1        1.4308        0.6667        2.15      0.0457
  AR1               1       -0.7526        0.1944       -3.87      0.0011

               Autoregressive parameters assumed given.

                                             Standard                 Approx
  Variable         DF      Estimate         Error     t Value    Pr > |t|

  Intercept         1       -0.0443        0.1431       -0.31      0.7606
  RDFTE             1        0.6165        0.2303        2.68      0.0154
  wsperhc           1        1.4308        0.6188        2.31      0.0328
```

The following section provides a summary of the statistical analysis conducted to estimate model parameters. See section **Error! Reference source not found.** for a detailed account of the statistical analysis.

The Regress R-Square 0.6812 statistic indicates that the model accounts for 68% of the variation of the percentage time spent by staff on R&D activities.

As the first model fitted with zero lag proves to have autocorrelation, an autoregressive model is fitted with lag = 1. The Durban Watson test was used to guage autocorrelation. The test statistic is 2.0372 with (Pr < DW = 0.4148) > 0.05 and (Pr < DW = 0.5852) < 0.95,, which indicates that the model does not have autocorrelation.

The colinearity test conducted on the data yielded that all the condition indexes from the regression model are smaller than the critical value. The conclusion can therefore be drawn that no colinearity is present. (For details on the test see paragraph x)

The tests for heteroscedasticity revealed that the error terms in the model are homoscedastic.

The Phillips Perron test used to test stationarity indicated that all variables included in the model are non-stationary. After the model was fitted, its residual was tested for stationarity. The test proved that the model residual is stationary and the variables are cointegrated. This implies that the regression is not spurious.

The estimated parameters are therefore defined in the following expression:

$$\ln(\frac{R_{Absorptionr}}{R^*_{Absorption}}) = f + d * \ln(\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}}) + e * \ln(\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}}) \tag{7-9}$$

The following table summarises the parameter values as well as the variance introduced into the parameter in the model. The variance is the standard error of the model as reported in the SAS output.

**Table 7-12: Summary of the Estimated Parameters for the Absorption of Knowledge**

| Parameter | Estimate | Variance (s.e.) |
|---|---|---|
| Intercept (f) | -0.0443 | 0.1431 |
| RDFTE | 0.6165 | 0.2303 |
| Wsperhc | 1.43 | 0.6188 |

These parameters with the variance values were used in the model, which yielded the following output for the absorption of knowledge, measured in terms of references made to scientific papers.

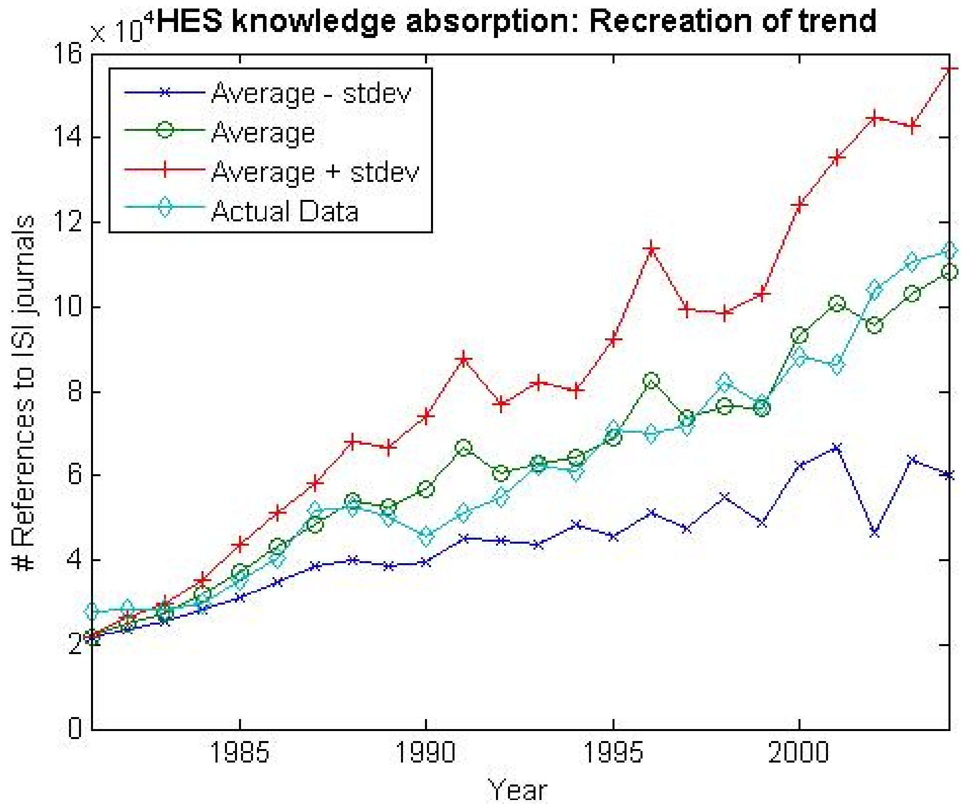



**Figure 7-14: Model Recreation of the Absorption of Knowledge Trend Data**

The coefficient of the determination ($R^2$), i.e. the fraction of the variance in the data explained by the model is computed to be 0.93, which indicates that the average of the model runs contains approximately 93% of the variation in the actual data.

The following section documents the analysis of the various scenario tests and what-if analysis run on the simulation model.

## 7.5 Model Simulation

These scenario tests run on the model were developed from the research questions as well as the Delphi study conducted. The Delphi study was instrumental in finding the most pressing issues facing the HES R&D system in South Africa. Using the Delphi study to develop the scenario tests ensured that the scenario tests developed were relevant in terms of the current concerns of experts working in the system.

The following table relates to the scenarios developed in the Delphi study (see section **Error! Reference source not found.**). The scenario tests run in this section are developed to answer the questions described in Table 7-13.

**Table 7-13: Scenario Tests runs executed on the Model**

| |
|---|
| **Base Case:** How could a constant/unchanging investment in the South African Higher Education system affect its ability to produce R&D output and absorb knowledge? |

**Scenario 1:** Experts foresee a lack of adequate funding for R&D projects in the HES for R&D projects. How could a decreasing level of investment in the South African Higher Education system affect its ability to produce R&D output and absorb knowledge?

**Scenario 2:** Experts foresee a deterioration of the quality of human resources in the system. How could the introduction of dedicated researchers in the system (science chairs) influence system performance in the development of centres of excellence?

**Scenario 3:** How could delaying to react on the decay of R&D capacity influence the system and the cost to rebuild lost capacity?

**Scenario 4:** How could the introduction of better time management skills in Academic and research personnel influence system performance?

### 7.5.1 The base case

The base case of the model simulation run is firstly to simulate the model behaviour for a specific scenario where as little as possible changes. The base case scenario is stated to have the following constants:

- the student numbers in the South African HES grows at 3% per year
- the investment in hiring new academic and research staff members grows with 3% per year, resulting in a 3% increase in academic and research staff; and
- the external environment has a 3% increase in knowledge production per year.

To test for the possible outcome in terms of the base case, 50 simulation runs were performed. The variability in terms of the standard error as predicted in the regression was included in the model to include the uncertainty in the parameter estimates from the regression analysis. The robustness of conclusions on the uncertainty in the assumptions also had to be tested for the model. The sensitivity analysis therefore aimed to test for the alterations in conclusions made from model output due to model sensitivity to parameter values.

In each figure, the average of the 50 runs as well as the trend lines for the standard deviations are indicated. The following section describes the model output as well as the conclusions that can be drawn from the sensitivity analysis.

#### 7.5.1.1 Base case: model output

The following figure represents the predicted rate at which the system will be absorbing knowledge from the external environment predicted under the base case conditions. It indicates that the system will continue to absorb knowledge from the external environment under the base case conditions.

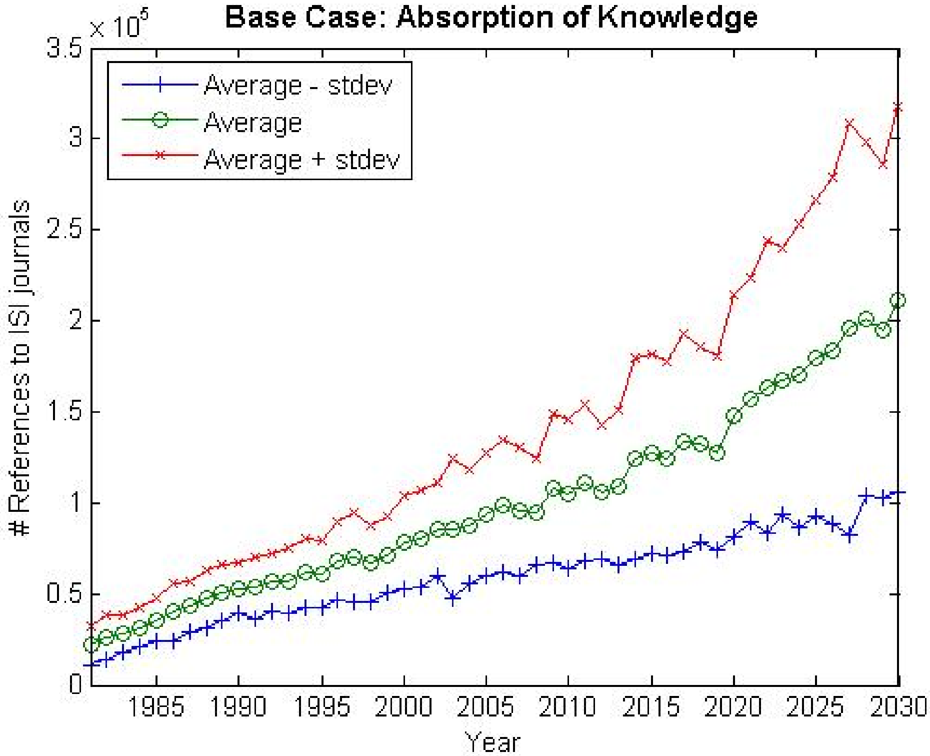



**Figure 7-15: Output from the HES Model for Knowledge Absorption Rate**

The following figure represents the predicted scientific paper creation rate by academic and research personnel in the South African HES. The figure yields that model output reveals that the scientific paper development rate of the system will continue to increase. This trend is to be expected as the base case scenario provides for a continued increase in A&R staff to sustain a constant student-to-staff ratio.

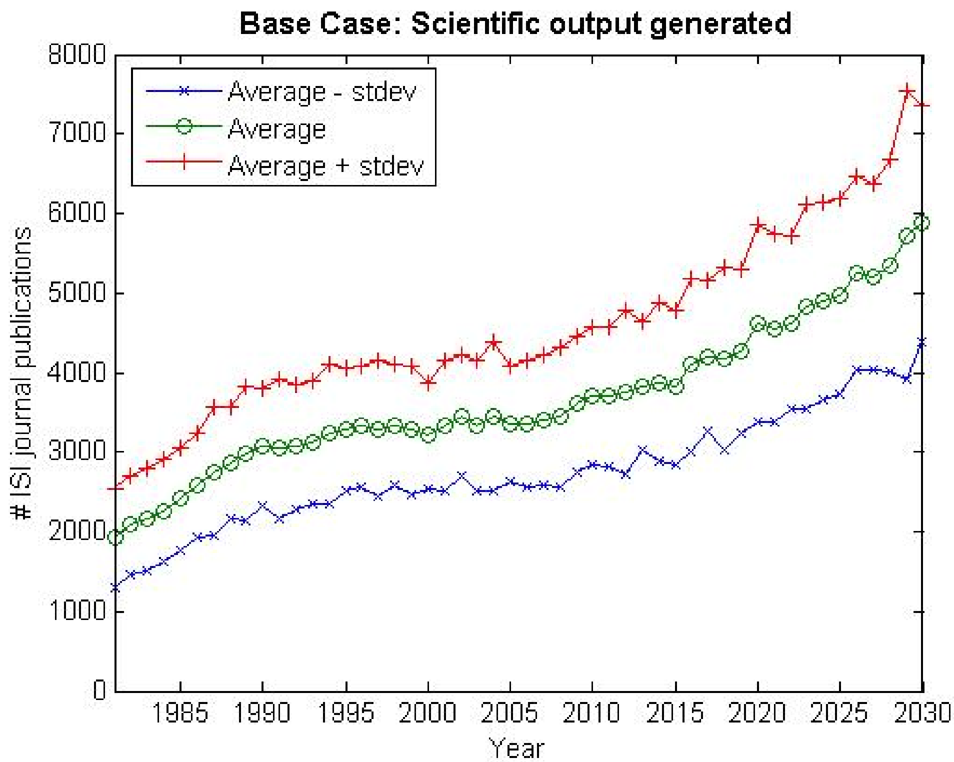



**Figure 7-16: Output from the HES Model for Scientific Output Development Rate**

An important parameter to consider is the scientific productivity of the researchers in the system. This refers to the amount of papers created per headcount personnel in the system. The following is a graphical representation of model output regarding the amount of papers per headcount academic and research staff in the system.

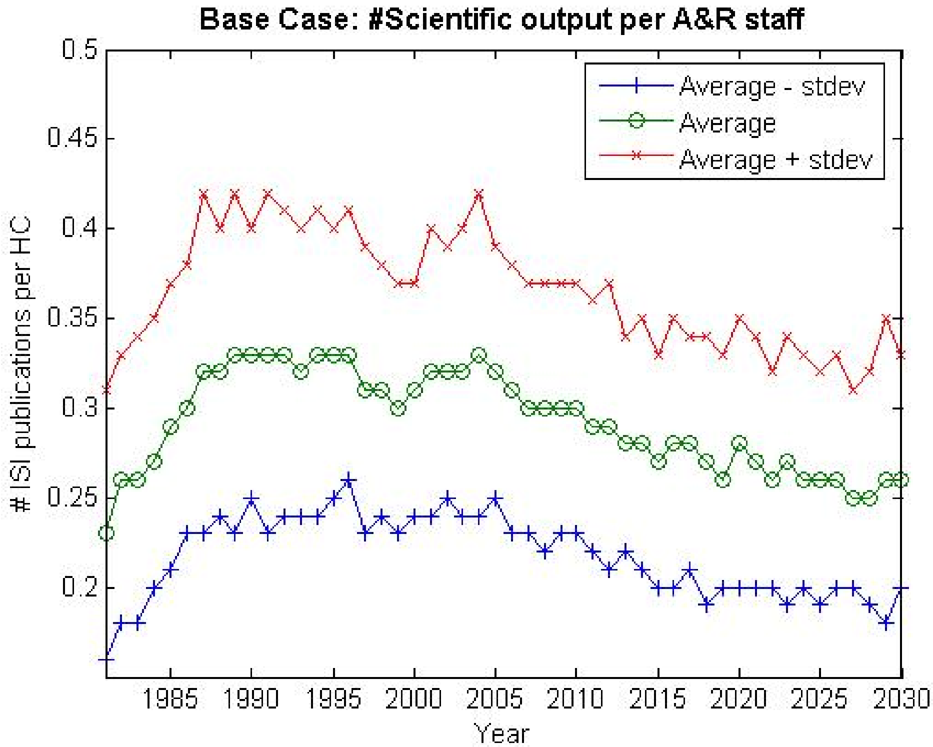



**Figure 7-17: Paper Productivity per Headcount in the HES**

The decrease in the percentage time that academic and research personnel in the HES spent on R&D over the past decade resulted in the decay of the experience stocks. This, in turn, results in the decay of knowledge stocks and levels of expertise of staff in the system, thus causing a lower productivity level per researcher in the system.

The following figure depicts the predicted share of South African scientific output in terms of world scientific output for the base case.

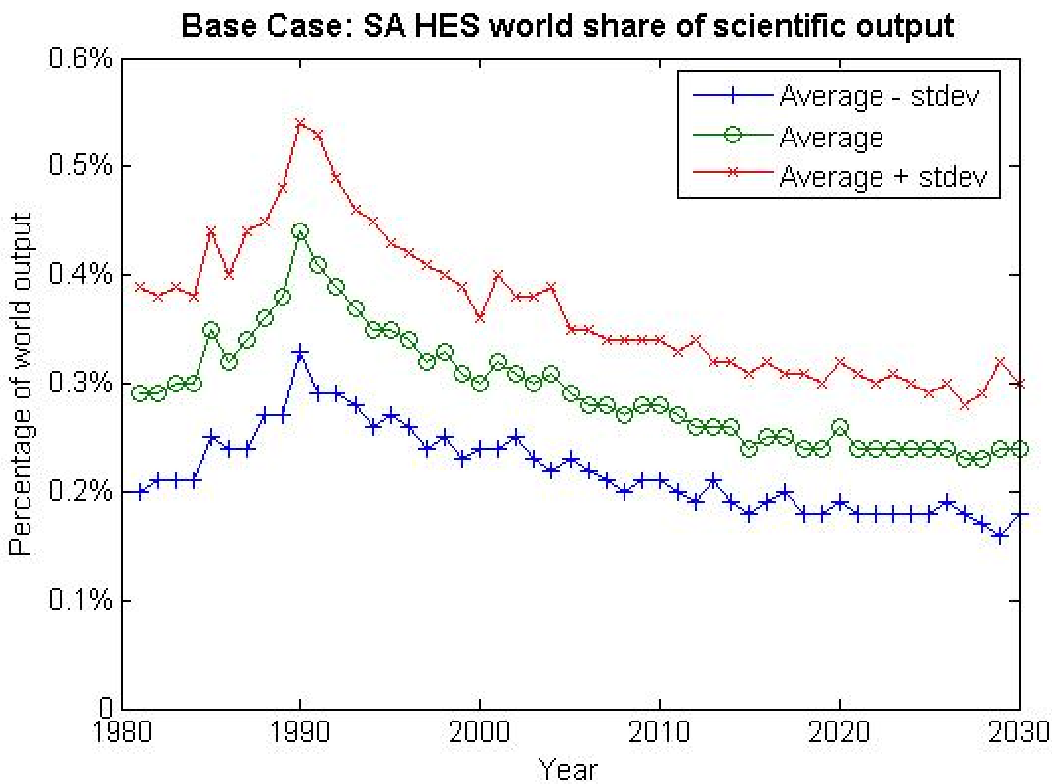



**Figure 7-18: Base Case Model Output for the South African World Share of Publcations**

The model predicts under base case conditions that despite the continued increase in R&D output, the South African share of world knowledge output might continue to shrink.

#### 7.5.1.2 Base case sensitivity analysis

The model output concludes that the model exhibits a numerical sensitivity to variability in the parameters in the system. We observe model sensitivity in terms of the output of scientific papers created in the system through the variability in the parameters in the production functions.

In the base case sensitivity analysis test, the model output demonstrates a numerical sensitivity to the starting values as well as variability in the parameters. All the graphs indicate the trend lines for the average calculated from the 50 runs as well as the trend lines for the standard deviation from the average as presented by the model.

The model does however not exhibit behaviour mode sensitivity, in other words the pattern of behaviour is not influenced by the variance introduced to parameters in the system.

Under the base case conditions, the model does not show any policy sensitivity, thus the changes in assumptions do not reverse the impact of the policy implemented.

We can therefore conclude that although the model is numerically sensitive, no changes in the behaviour of the model as well as the outcome of the policies are evident from model output.

### 7.5.2 Scenario 1

The purpose of Scenario 1 is to scrutinise the predicted model output for different rates of investment increases in the HES. The scenario test that is run has the following constants:

- fixed student growth rate of 3% in the system
- external knowledge creation increasing at 3% per year; and
- salaries remain constant.

The following table summarises the scenario test run inputs and the different runs executed. The rate at which the academic and research staff increases per year is varied from 0% to 6% per year.

**Table 7-14: Test Run for Scenario Testing**

| | Percentage Growth Rate in HES Investment | Sensitivity Analysis |
|---|---|---|
| Run 1 | 0% per year | 50 runs with 30% variability |
| Run 1 | 1% per year | 50 runs with 30% variability |
| Run 1 | 2% per year | 50 runs with 30% variability |
| Run 1 | 3% per year | 50 runs with 30% variability |
| Run 1 | 4% per year | 50 runs with 30% variability |
| Run 1 | 5% per year | 50 runs with 30% variability |
| Run 1 | 6% per year | 50 runs with 30% variability |

A sensitivity analysis was also performed on the different scenario runs to test for numerical-, behavioural and policy sensitivity. A total of 30% variability is introduced in all parameter and starting values of stocks. The sensitivity outcomes are discussed at the end of this section.

#### 7.5.2.1 Scenario 1: Model output

These test runs yield the following output in terms of the people employed in the system. These outputs indicate quite clearly that a significant increase in human resources in the system will be needed to facilitate higher growth rates.

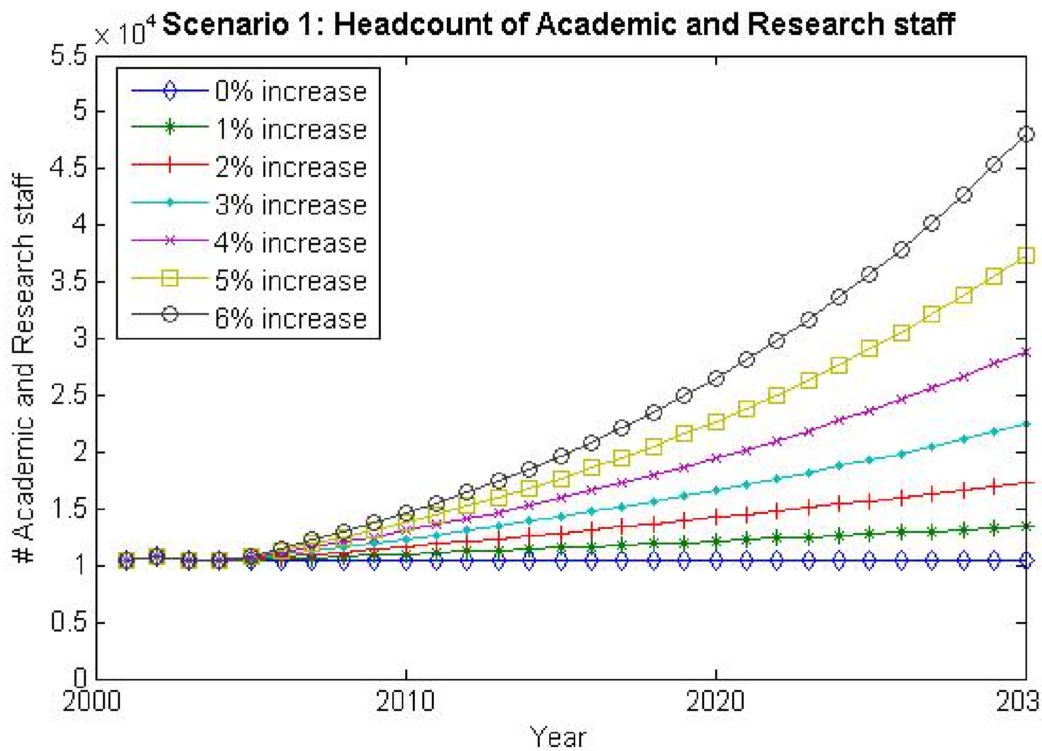



**Figure 7-19: Academic and Research Personnel at Universities in South Africa**

At a 3% growth rate, the system will seek to almost double the amount of human resources it has in the year 2003 by the year 2025. Figure 7-19 demonstrates that the higher growth rates have a much shorter period before the human resources employed in the system doubles.

The increase in expenditure on the human resources in the system has an implication on the rate that the human resources stock is growing in relation with the student stock, thereby influencing the amount of people working in the system per student enrolled at universities. Figure 7-20 is a graphical representation of the student-to-staff ratio in the different test runs in the model.

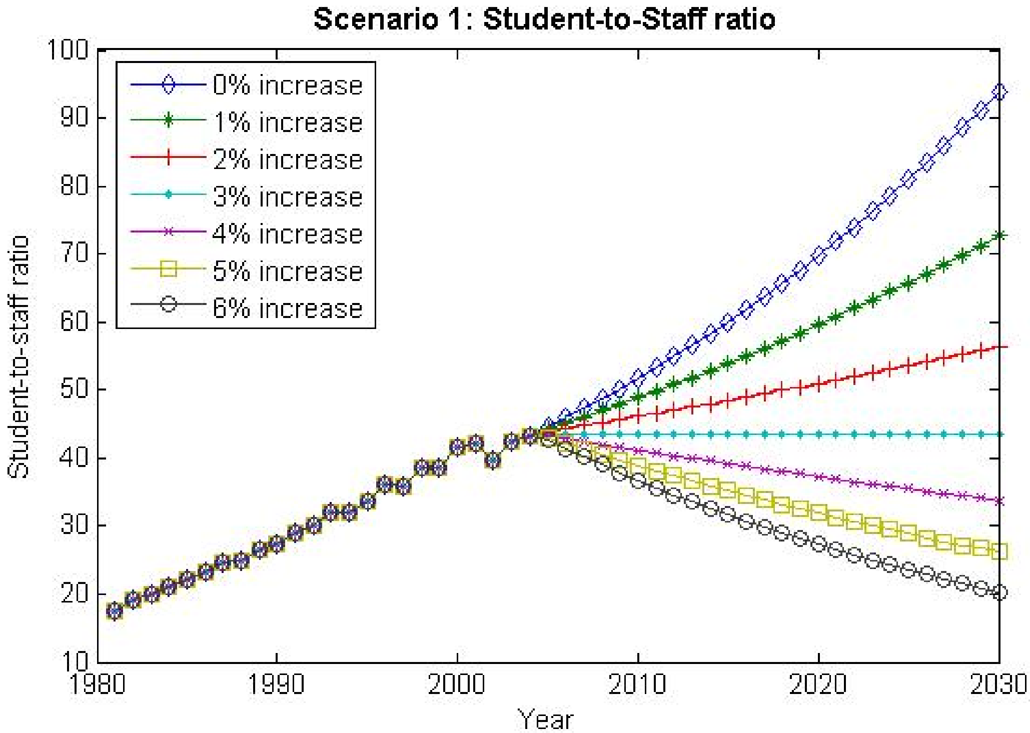



**Figure 7-20: Scenario 1 - Student-to-Staff Relationship for the Simulation Runs**

The student-to-staff ratio has direct implications on the time that academic and research staff is able to spend on R&D activities. Figure 7-21 indicates this effect on the percentage time researchers have left to spend on R&D activities.

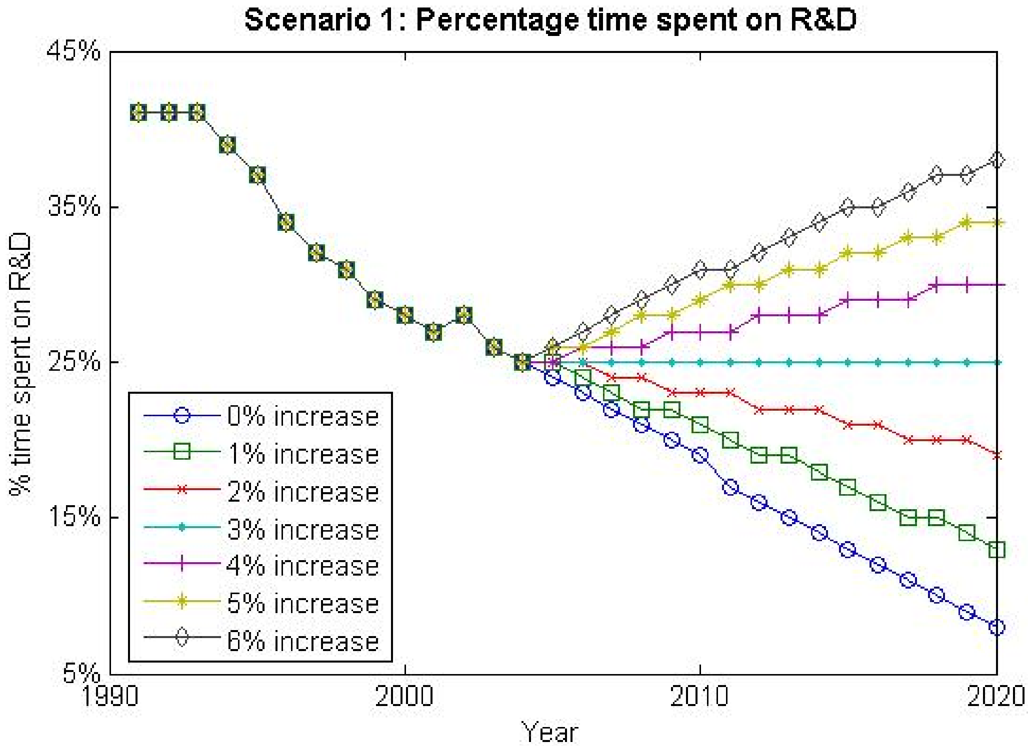



**Figure 7-21: Percentage time spent on R&D Activities by Academic and Research Staff**

A higher percentage of time spent on R&D leads to a higher level of the development of experience in the system as well as an increase in the amount of people concentrating on the development of R&D. Through this dynamic, the system exhibits an increase in scientific output produced per headcount in the system.

For each of the scenarios of 0 to 6% increase in research staff in the system, 50 runs were executed. Figure 7-22 is a graphical representation of the average trend from the runs for each growth scenario.

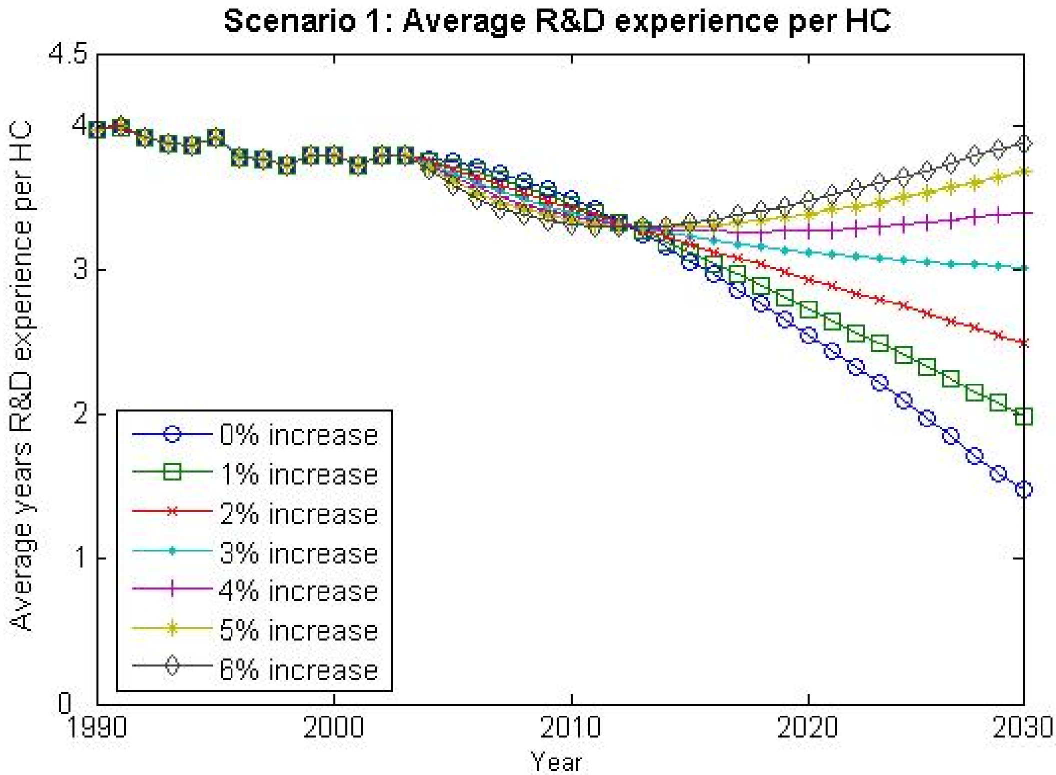



**Figure 7-22: Scenario 1: Avg Experience in R&D per HC**

Again, the average of the 50 runs for each scenario is calculated from the model output. The experience stock of the academic and research staff in the system demonstrates an interesting trend. For the 4% - 6% growth rates the average R&D experience per headcount in the system decreases before it starts to increase.

A sudden influx of A&R staff with no prior R&D training explains this dynamic. The student-to-staff relationship has not yet increased significantly to allow for a larger percentage time spent on R&D to balance the increase of untrained A&R staff.  This results in a decrease in average experience per person. As the student-to-staff ratio increase, staff will have more time to spend on R&D. This, in turn, will result in staff building up more experience, which will raise the average experience per person in the system.

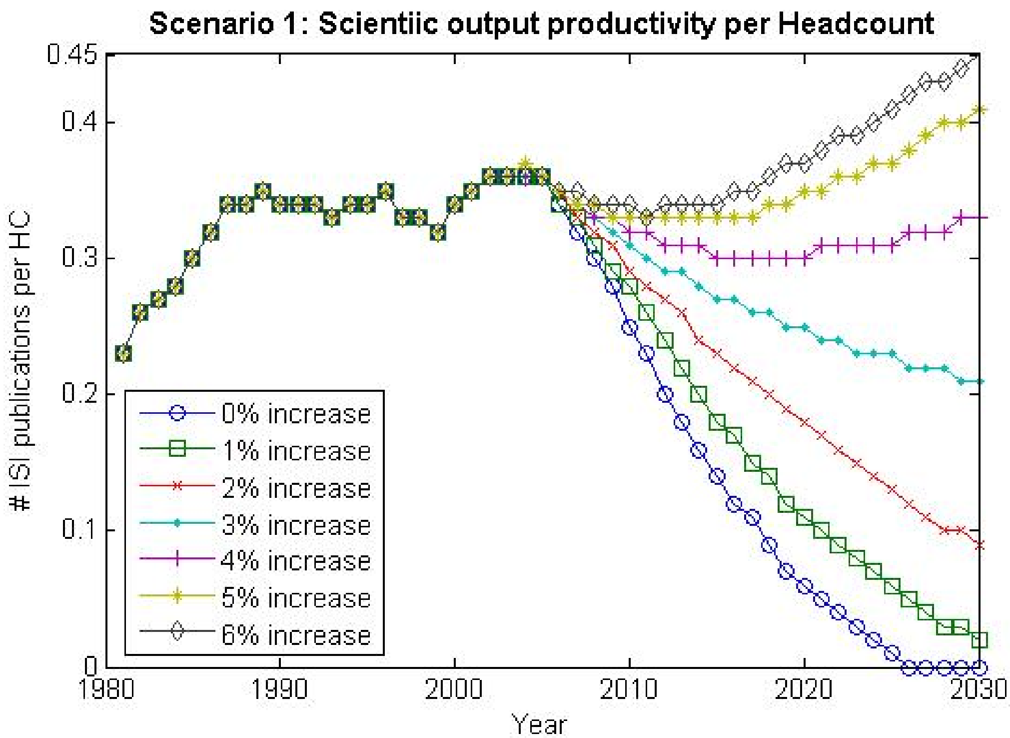



**Figure 7-23: Scenario 1: Productivity per Headcount Employed in the System**

It is clear that the amount of papers produced per headcount in the system is heavily influenced by the different policy tests implemented. Figure 7-23 reveals that the predicted amount of ISI publications per headcount in the system will start to increase as the system dynamics deal with the effects of more A&R staff in the system.

The effect of the investment on the system's ability to produce knowledge is measured by the amount of papers published in ISI journals. The following figure depicts the model output generated in the system for the different rates of investment increases.

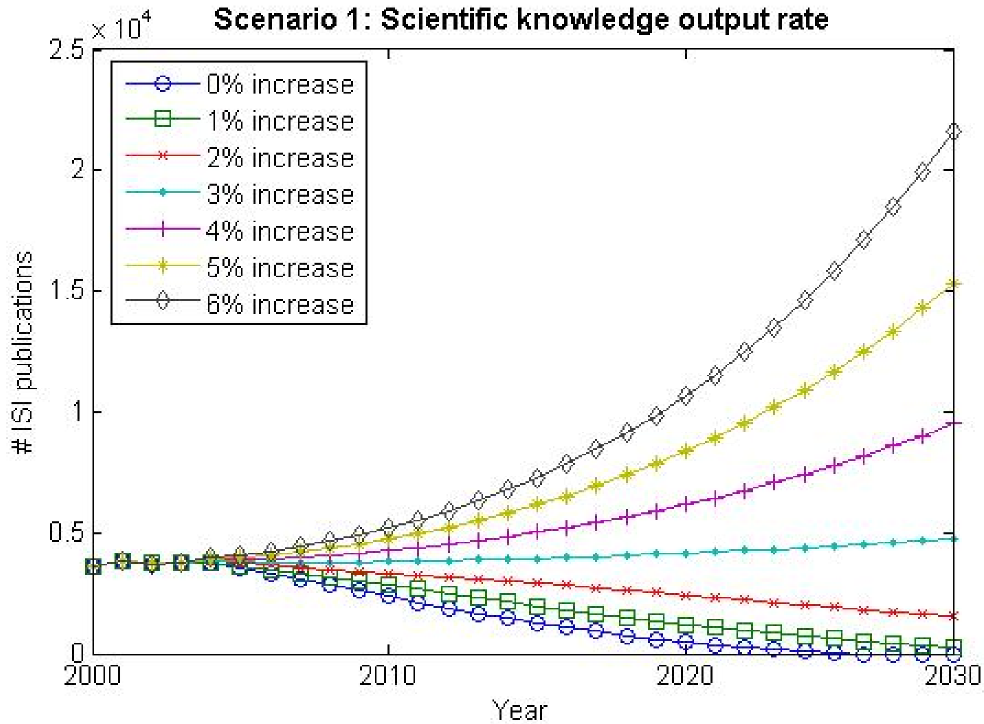



**Figure 7-24:** **Scenario 1: Rate at which new R&D Outputs are created in the HES**

It is clear that an increase in the investment in the human resources in the system results in rise in the number papers produced per staff member as well as the number of research staff in the system, thus resulting in an exponential increase in R&D output developed in the system (Figure 7-24).

The effect of R&D investment on the system's ability to assimilate knowledge is measured by the rate at which people in the system absorb knowledge for the creation of new R&D outputs, which is, in turn, measured by the number of references made to the papers published in ISI journals. Figure 7-25 provides a graphical representation of the data output generated by the model.

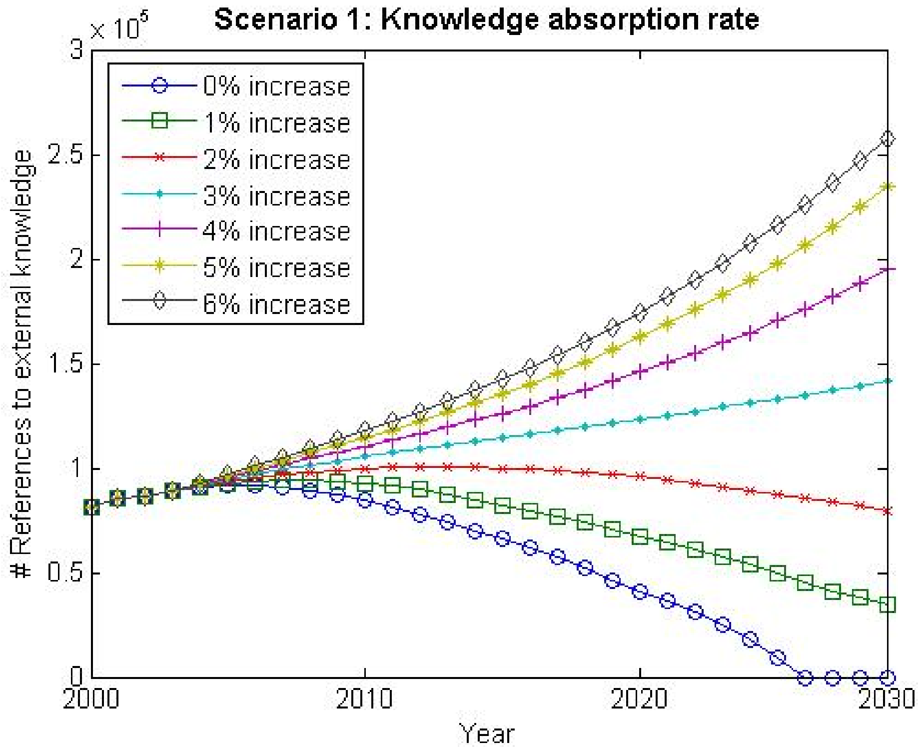



**Figure 7-25: Scenario 1: Knowledge Absorption Rate**

The system is not in isolation and the ability to keep up with the world is also impacted through the lack of investment in the development of an R&D capacity in the system. Figure 7-26 provides a graphical representation on the projected world share of R&D output in South Africa's R&D system.

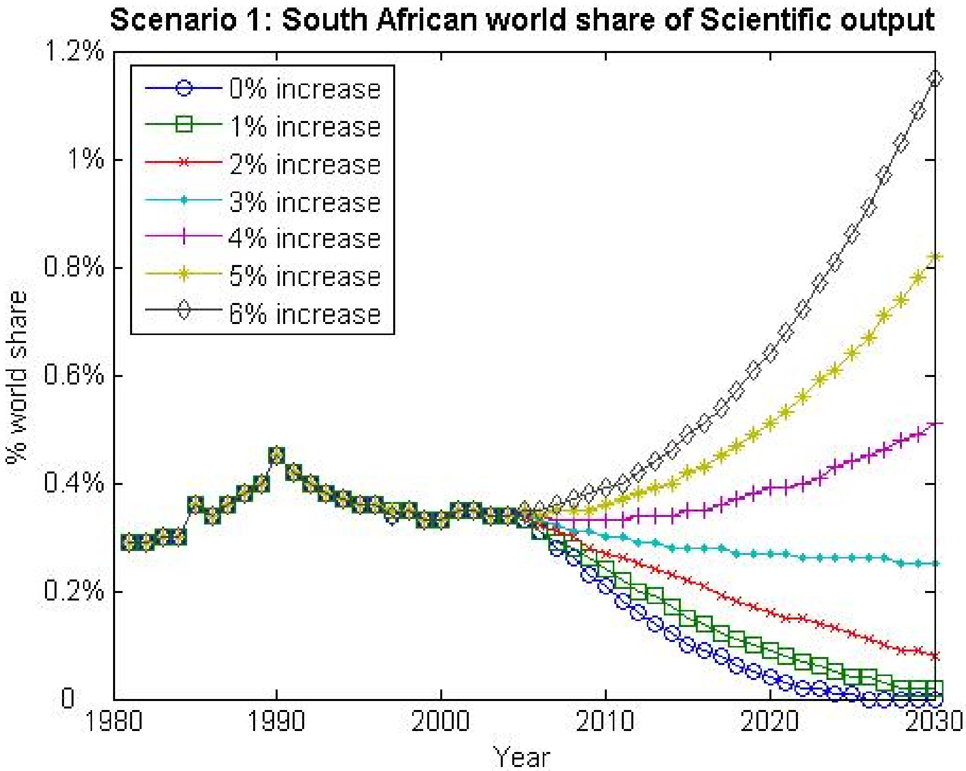



**Figure 7-26: Scenario 1: Projected HES Share of Scientific Output in the World**

The graph clearly indicates that the predicted trend in the model is that the South African system's world share in knowledge creation could continue to shrink, should the current levels of investment continue. Considerable growth and nurturing of the R&D workforce is thus necessary to ensure that South Africa improves its international position as knowledge creator.

### 7.5.2.2 Scenario 1: Sensitivity analysis

Very basic sensitivity analysis tests were conducted. The following figure represents the box plots of the average amount of papers produced for the seven different scenario runs.

For the 50 runs for each of the scenarios of an increase from 0% to 6% in R&D investment, the average papers produced in the HES from 2002 to 2030 is computed. An exponential increase in the average paper produced per person is evident.

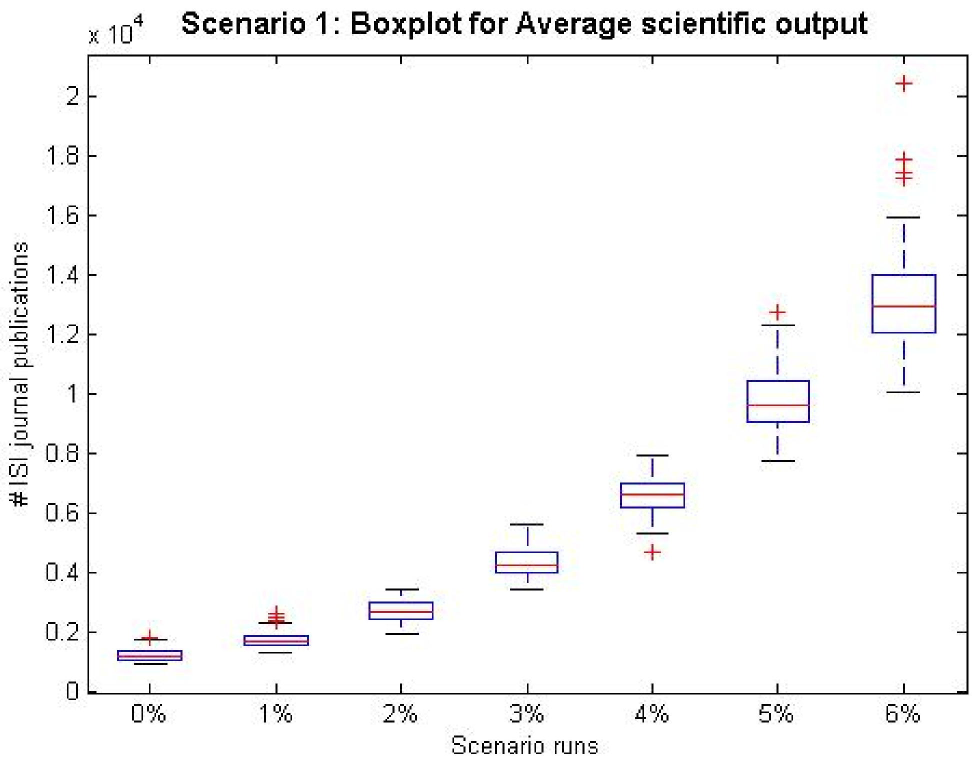



**Figure 7-27: Scenario 1: Box Plot for Average Scientific Output Generated in the HES**

Where the change in the investment rate increases from 0% to 6%, the uncertainty and the variance in the average outcome computed also shows an increase (Figure 7-27). More uncertainty exists regarding the system's reaction to change if the changes made to the system are extensive.

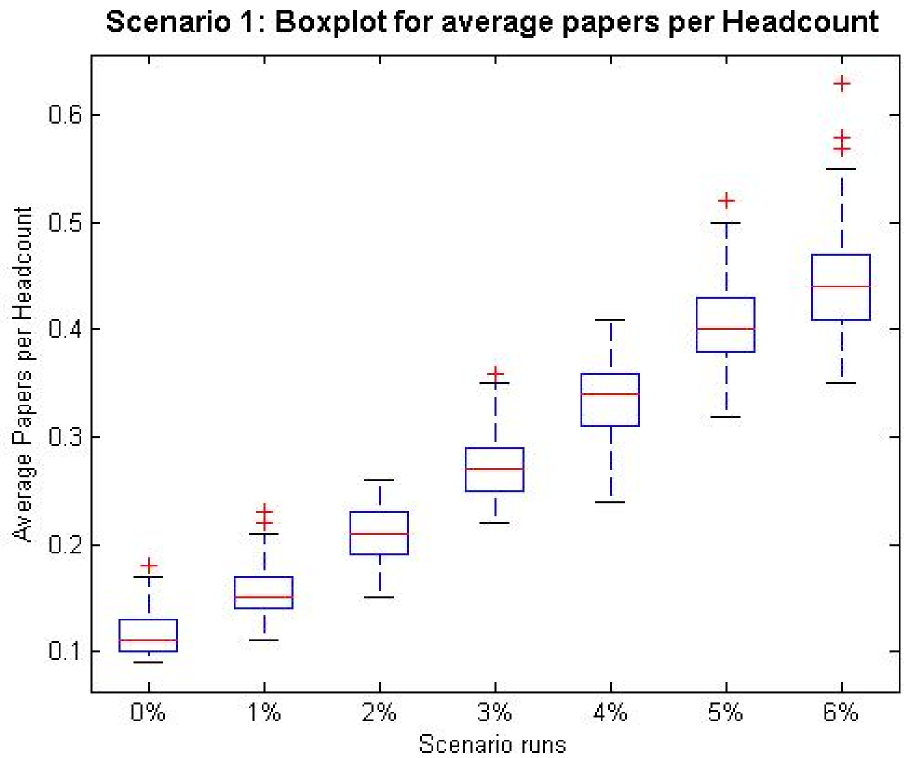



**Figure 7-28: Scenario 1: Box Plot for the Average Paper per Headcount Generated**

For the different scenarios (ranging from 0 to 6% increase in expenditure), the average amount of papers produced per headcount was computed. It is clear that the average increases at a trend that appears to be linear.

A model suffers from policy sensitivity if the assumptions made regarding the system's performance under a specific policy might lead to different system behaviours. However, the box plots and the outcomes in Scenario 1 clearly indicate that the policies' outcomes are not influenced by the sensitivity. The model follows a certain trend.

We can therefore conclude that mainly numerical sensitivity can be seen in the model output.

### 7.5.3 Scenario 2

The purpose of Scenario 2 is to test model behaviour under a condition of implementing a policy of research chairs in the HES. The student-to-staff ratio is kept constant at a specific level after which the rest of the academic and research staff is allowed to spend all their time solely on research activities.

System variables are set to the following constant for the purpose of this test run:

- fixed student growth rate of 3% in the system following recent trends
- external knowledge creation is increasing at 3% per year following recent trends
- salaries remain constant; and

- the system dedicates researchers to be part-time research staff to maintain the student-to-staff ratio of 40 students per staff member. All extra appointments are dedicated research personnel.

A simple dynamic is introduced into the model where the current student-to-staff ratio is compared to the target student-to-staff ratio. Should the system employ too little staff members to satisfy the target student-staff rate, the increase in human resources employment in the sector is devoted to employing more lecturers. If the reverse is true, the system uses the money to employ new, fulltime researchers. These fulltime researchers are assumed to spend approximately 70-80% of their time on R&D activities.

**Table 7-15: Growth Trends in Expenditure Run 1 to 6 in Scenario 2**

| # | % increase in expenditure | |
|---|---|---|
| Run 1 | 0% per year | 50 runs with 30% variability |
| Run 2 | 1% per year | 50 runs with 30% variability |
| Run 3 | 2% per year | 50 runs with 30% variability |
| Run 4 | 3% per year | 50 runs with 30% variability |
| Run 5 | 4% per year | 50 runs with 30% variability |
| Run 6 | 5% per year | 50 runs with 30% variability |
| Run 7 | 6% per year | 50 runs with 30% variability |

#### 7.5.3.1 Scenario 2: Model output

The first output presented is the effect of the dynamic included of assigning new appointments to science chair positions to in the system. It is clear from Figure 7-29 that as soon as the growth rate of the academic and research staff stock exceeds the growth rate of the student stock; the student-to-staff rate remains constant at 40 students per staff member.

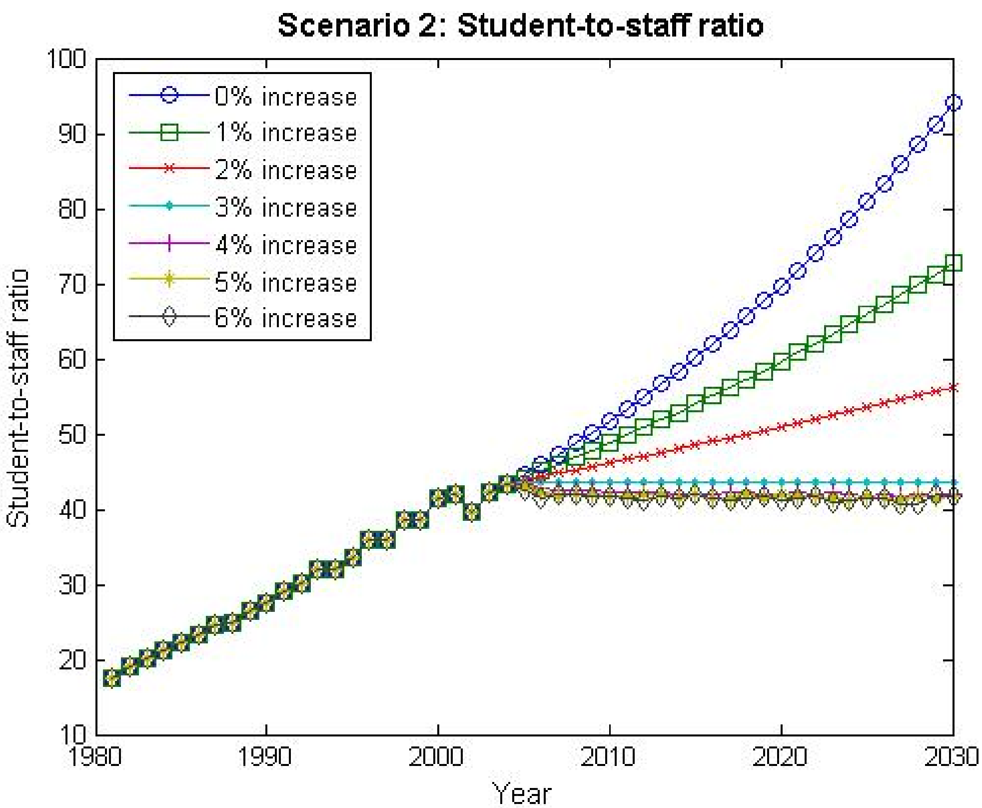



**Figure 7-29: Scenario 2: Student-to-staff Ratio**

It is therefore clear that the system will only benefit from the policy tested in this scenario for research chair positions once the rate of increase of the academic and research staff exceeds the student growth rate.

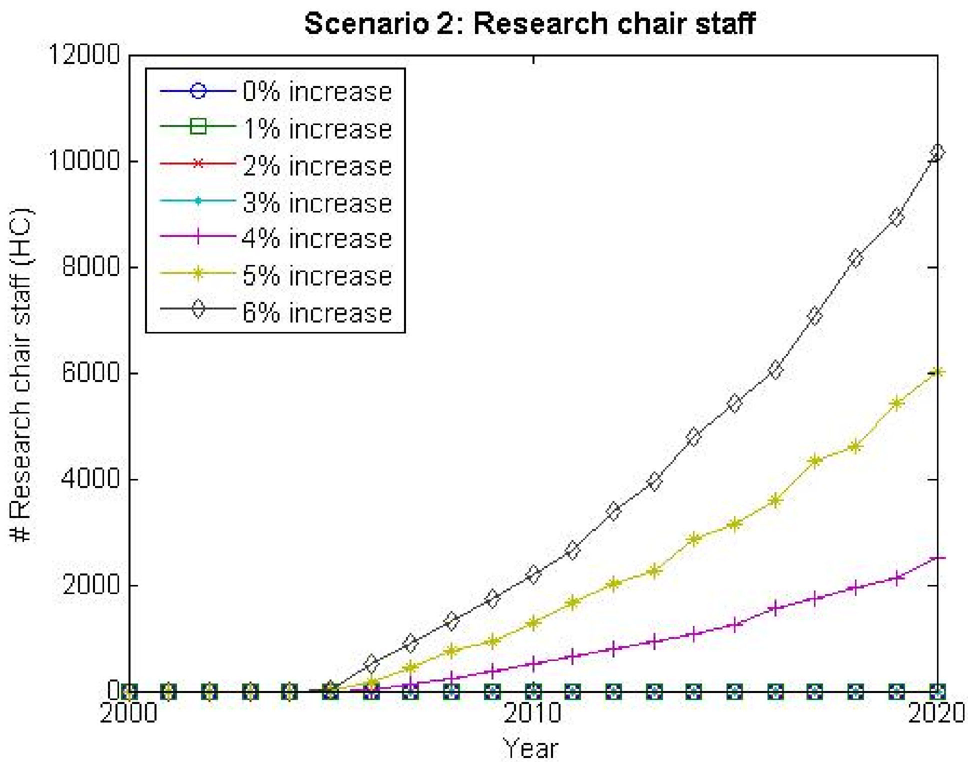



**Figure 7-30: Scenario 2: Research Chair Positions in the South African HES**

Figure 7-30 indicates that as the growth rate of academic and research staff exceeds that of the student increase, research chairs will be assigned in the system. Since the staff employed on the research chair positions will be spending most of their time purely on research duties, the experience built up by these staff members will also increase above the base case level. The average level of experience in the system will therefore result in a more productive workforce.

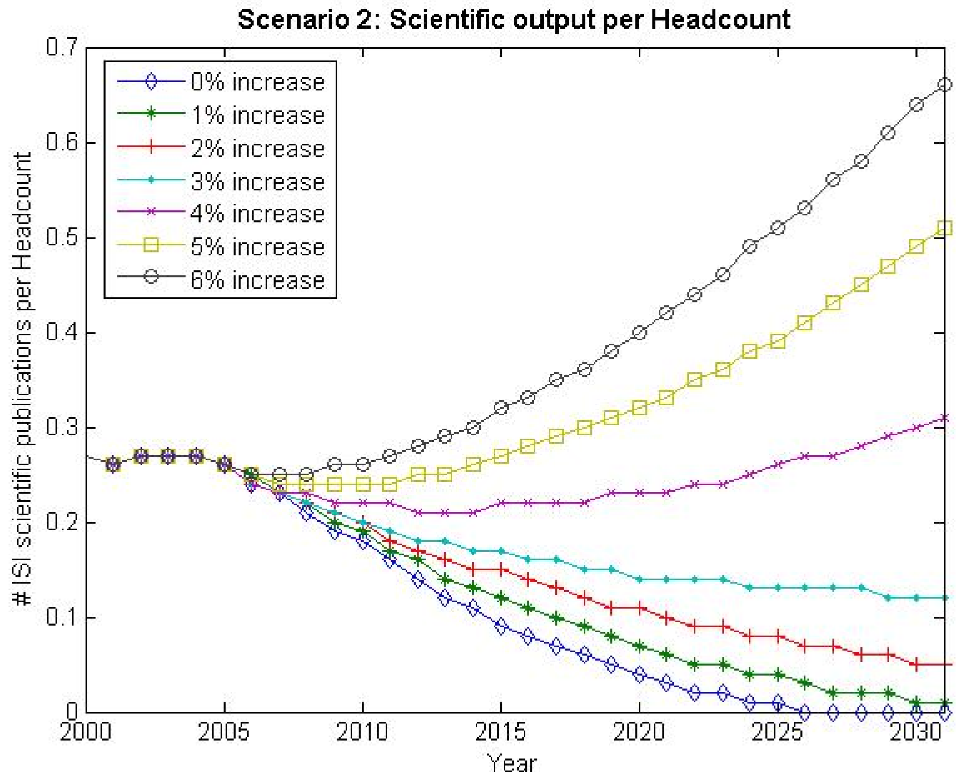



**Figure 7-31: Scenario 2: Paper Productivity per Headcount Staff Employed in the System**

An increase in the average papers produced per headcount personnel in the system is achieved as more people are assigned to research chairs. Due to this increase, the rate of paper production also increases as the system assigns staff to fulltime research positions.

A comparison of the model behaviour regarding the papers produced per headcount employed in the system of Scenario 1 and Scenario 2 can be drawn. An average is calculated for the model's predicted output over the years 2010-2020 for both these scenarios.

| | **Average @ 3%** | **Average @ 4%** | **Average @ 5%** | **Average @ 6%** |
|---|---|---|---|---|
| Scenario 1 | 0.211 | 0.232 | 0.243 | 0.249 |
| Scenario 2 | 0.211 | 0.246 | 0.293 | 0.327 |

The model output clearly indicates that the amount of science chairs in the system increases as the investment rate rises. This ultimately results in a higher average experience per person in the system, which is the main contributing factor to the increased productivity of human resources in the system. It thus appears that the Scenario 2 setting will yield the best results for higher levels of investment.

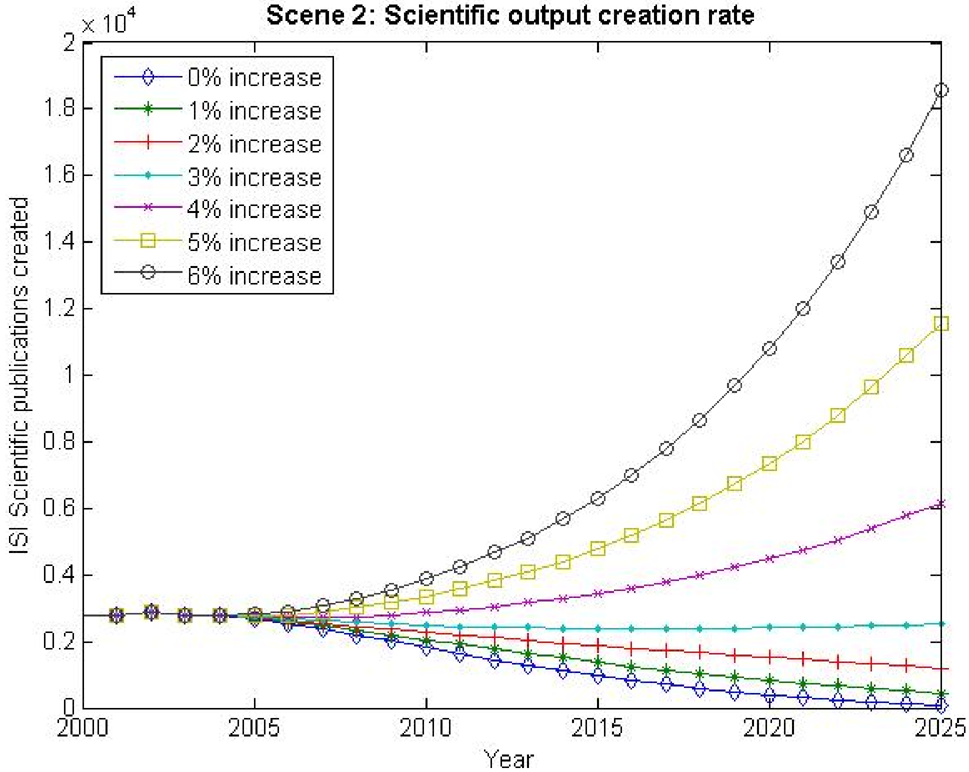



**Figure 7-32: Scenario 2: The Ability of the System to Create New Knowledge**

In Figure 7-33, the model output of the South African R&D system's R&D output as a percentage of the world share of papers produced in South Africa is presented. Once again it is apparent that where investment levels exceed the student stock growth rate of 3%, South Africa's competitive position as a knowledge creator is bound to improve.

A comparison can be drawn by calculating the average papers that will be produced in the system over the years 2010 - 2020 for both Scenario 1 and Scenario 2.

| | **Average @ 3%** | **Average @ 4%** | **Average @ 5%** | **Average @ 6%** |
|---|---|---|---|---|
| Scenario 1 | 3081 | 3837 | 4575 | 5281 |
| Scenario 2 | 3081 | 4113 | 5547 | 7069 |

It is clear that the predicted output for Scenario 2 leads to an increased scientific output rate as the growth rate of the system increases.

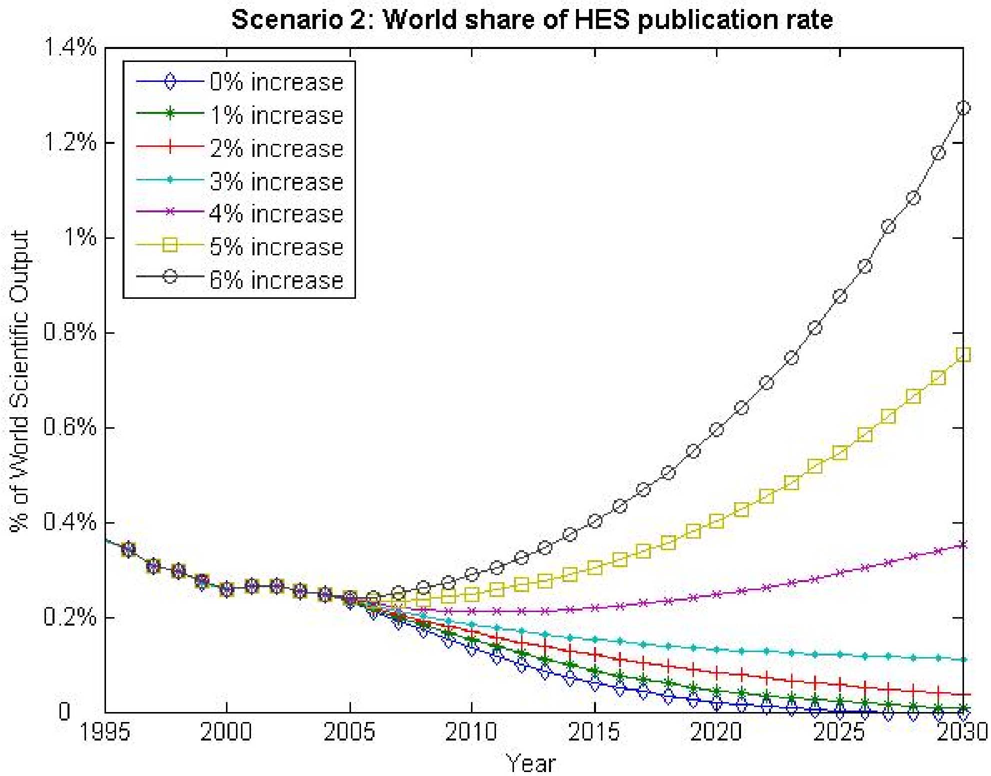



**Figure 7-33: Scenario 2: The South African Share of Scientific Output**

The higher contribution to the international science output is evident in the comparison of the Scenario 1 and Scenario 2 model output.

| | Average @ 3% | Average @ 4% | Average @ 5% | Average @ 6% |
|---|---|---|---|---|
| Scenario 1 | 0.22 | 0.27 | 0.31 | 0.36 |
| Scenario 2 | 0.22 | 0.28 | 0.37 | 0.46 |

It can therefore be concluded that a policy of introducing science chairs could yield positive results for the South African HES.

#### 7.5.3.2 Scenario 2: Sensitivity analysis

A sensitivity analysis was conducted on the output of the model under the Scenario 2 conditions by examining the outcomes of the different policy assumptions as well as the numerical sensitivity of the model to variability in estimated parameters.

This clearly indicated that the model output of Scenario 2 is similar to that of Scenario 1 for investment rates of 0% to 3%. As the staff growth rate exceeds that of the student-to-staff growth rate, the policy of research chairs takes effect.

The model output suggests that an increase in capacity could be gained by assigning people to research positions. Such a strategy may result in the system building up higher levels of average experience, thus leading to higher levels of R&D capacity in researchers in the system.

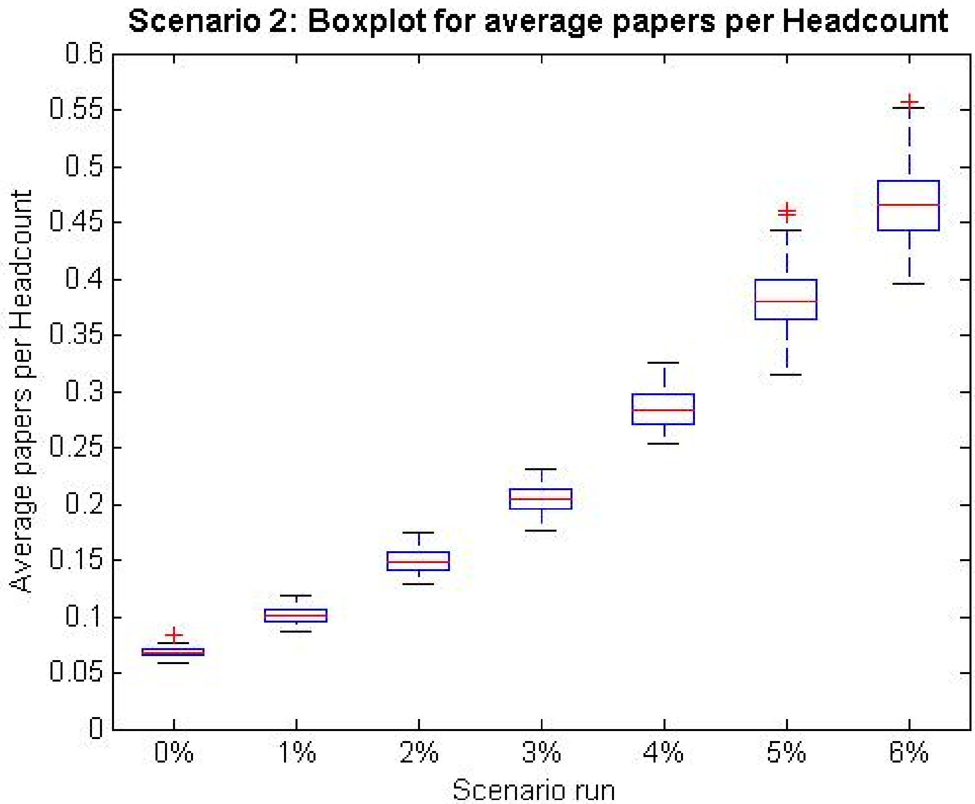



**Figure 7-34: Scenario 2: Box Plot for Avg. Papers per Headcount Produced in the HES**

Figure 7-34 is a graphic representation of the model output of the average papers produced per headcount the system for the years 2010 - 2030. These box plots indicate that for investment rates of 0% to 6%, the system progressively possess a higher level of numerical sensitivity than for the lower levels of investment growth.

It is therefore evident that the system does have numerical sensitivity to parameters and policies implemented. The output of the simulation runs does however not indicate any policy sensitivity in the model.

### 7.5.4 Scenario 3: The cost of system decay

This scenario test aims to investigate cost implications and the effect that disinvestment in R&D might have on the system. The experiment executed on the model investigated the effect that a delayed reaction might have on the shrinking percentage of time that academic and research staff has left to perform research duties.

The scenario test has the following constants:

- fixed student growth rate of 3% in the system, following recent trends
- external knowledge creation is increasing at 3% per year, following recent trends;

and
- salaries remain constant.

Since recent data of the student-to-staff relationship in the HES indicates that staff is constantly spending less time on R&D activities, an experiment was conducted to investigate the effect of delaying to react on this problem.

In this scenario, the level of investment and the level of fulltime personnel in the system are assumed to remain constant until a policy of increasing the staff is taken. Simulation runs are conducted on the model to test for different growth rates with different periods of delay before they are implemented.

Different scenarios are run, building up a matrix of scenario values represented by the following grid:

| | **0%** | **1%** | **2%** | **3%** | **4%** | **5%** | **6%** |
|---|---|---|---|---|---|---|---|
| **2004** | | | | | | | |
| **2005** | | | | | | | |
| **2006** | | | | | | | |
| **2007** | | | | | | | |
| **2008** | | | | | | | |
| **2009** | | | | | | | |
| **2010** | | | | | | | |
| **2011** | | | | | | | |

The simulation model is run for different scenarios with policies being implemented from 2004 to 2011. For each of these starting dates, different growth rates ranging from 0 to 6% are tested.

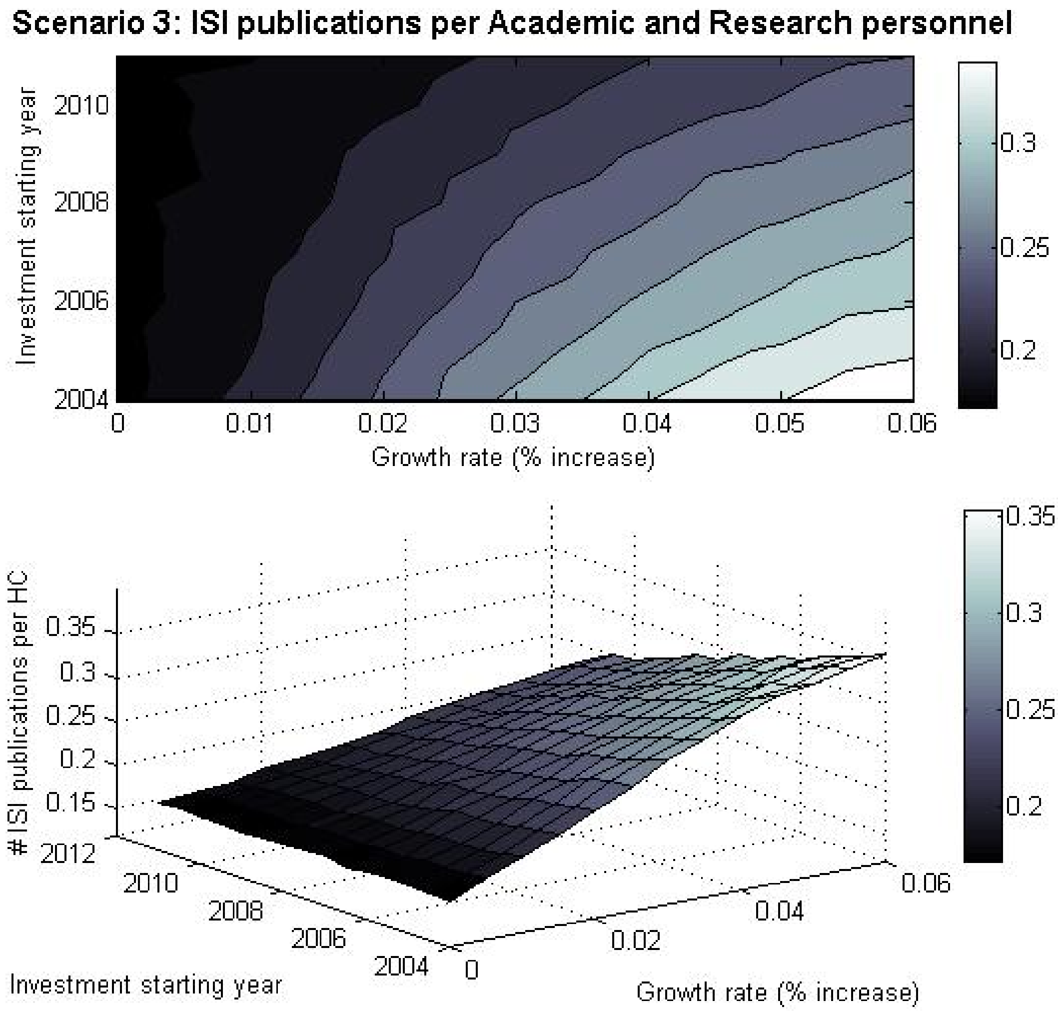



**Figure 7-35: Scenario 3: ISI Publications per Academic and Research Personnel**

The effect of the policy is measured in terms of the average percentage time that academic and research staff spends on R&D activities. For each scenario run, i.e. for a specific growth rate and a specific year as represented in the grid, the average model output is computed and presented in Figure 7-35. The average over the period 2010 to 2030 was then calculated.

Colour coding for a specific range of values in the contour map and the surface plot clearly indicates that scenarios with later start dates need much higher rates of investment to achieve a similar result.

This trend can also be observed in the contour and surface plots of the model output of publications generated in the system. For each scenario run, the average model output of predicted scientific publications generated in the HES is computed and presented in Figure 7-36. The average over the period 2010 to 2030 was once again taken.

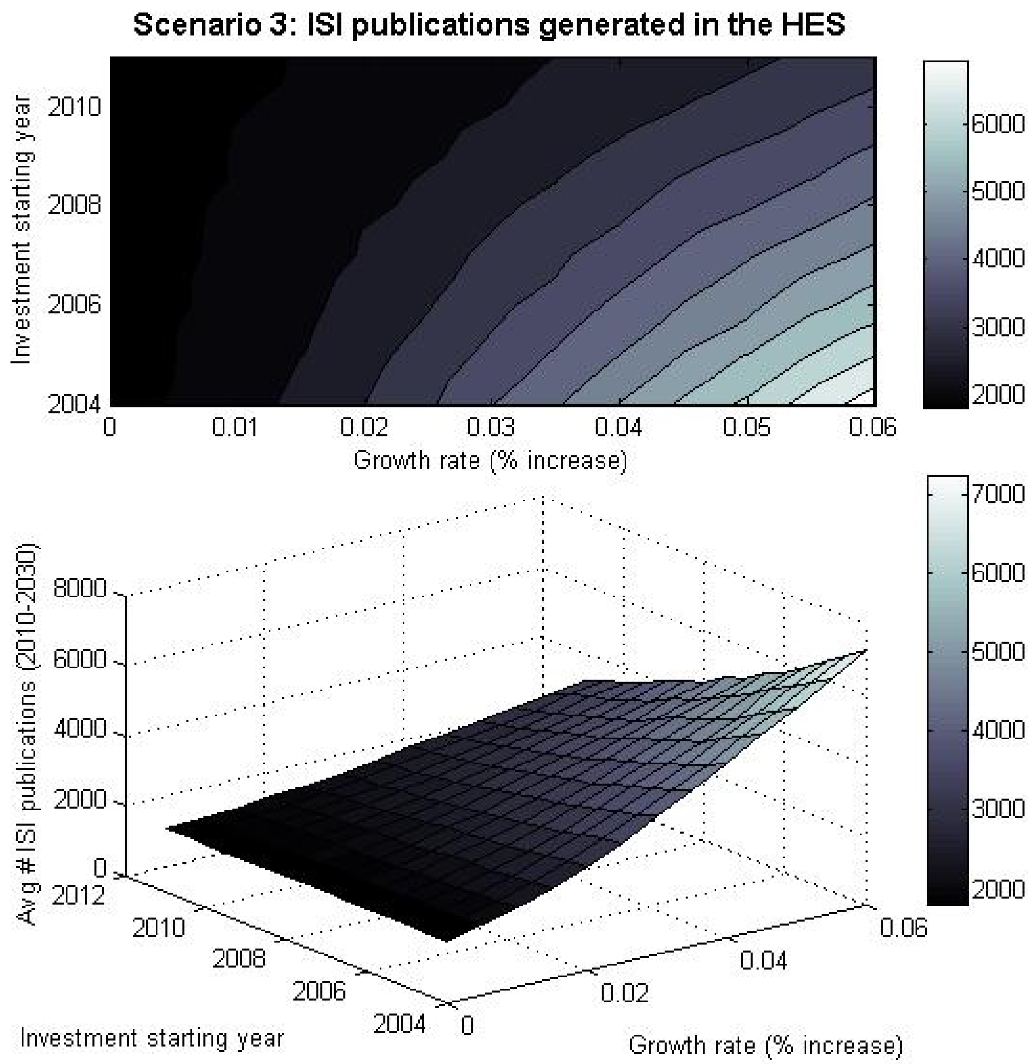



**Figure 7-36: Scenario 3: ISI Publications Generated in the HES**

The decay of capacity and the inability to react on the system's decay will result in the system demonstrating a much lower scientific output rate.

We can therefore conclude that rebuilding the lost capacity would prove extremely costly, should the system be allowed to decay. Thus, if the system is allowed to loose capacity, a much higher investment will later be needed to rebuild the system and regain the levels it once had.

### 7.5.5 Scenario 4: Time management of staff

This scenario test aims to investigate the effect that improved time management amongst academic and research staff might have on the system. The experiment executed on the model investigated the effect that an improvement in the percentage time left for R&D after attending to lecturing duties might have on the system. In other words, the effect that the increasing student-to-staff ratio has on the shrinking percentage time that academic and research staff has left for research duties could be countered by implementing policies aimed to improve personnel's time management.

This exercise is purely speculative and can consequently not be based on any empirical findings from the South African R&D system. Evidence does however exist in the literature of improvements in the productivity in researcher output through 'publish or perish' incentives (McGrail et al, 2006).

The calculation of the transfer function presented in Figure 7-37 is derived from the equation estimated in section 7.4. The equation is modified to account for a percentage improvement in the effect that the students per staff member might have on the time that academic and research staff has left for R&D. The modified equation is as follows:

$$\%Time\_on\_R\&D = 0.58592 + (-0.16677)*(1-\%improvement)*\frac{StudentStaff\,\mathrm{Re}lationship}{StudentStaff\,\mathrm{Re}lationship^{*}}$$

Where $StudentStaff\,\mathrm{Re}lationship^{*} = 26.15$ **7-10**

The following figure is a graphic representation of the improvement that time management could have on the time left for researchers to spend on R&D.

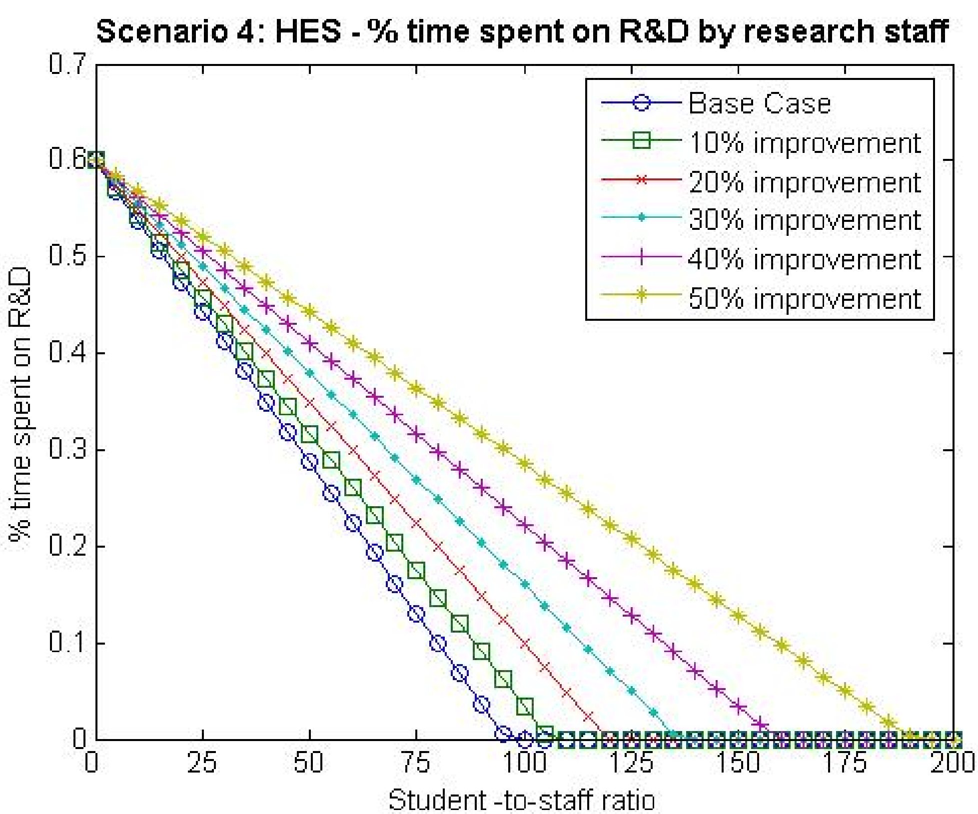



**Figure 7-37: Scenario 4: Effect of % improvement on time spent on R&D**

The transfer function as depicted in Figure 7-37 is incorporated in the scenario test for changes that an improvement in the time management of researches might have on the R&D capacity in the system.

The scenario test has the following constants:

- fixed student growth rate of 3% in the system, following recent trends
- external knowledge creation is increasing at 3% per year, following recent trends; and
- salaries remain constant.

A what-if analysis is performed on the system by constructing a matrix of scenarios represented by the following grid. The effects of changes in the system are tested along two axes:

- axis 1: change in the R&D expenditure in the system, i.e. change from 0% to 6% increase per year in expenditure in the HES; and
- axis 2: change in the improvement in time management by academic and research staff, i.e. change in time management improvement of 0% to 50%.

A test was performed on the system's reaction to changes in the time management of academic and research staff as well as the funding in the system.

**Table 7-16: Scenario 4: Changes in System Constants along Two Axes**

| | | Increase in Investment Rate | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Improvement in Time Management** | | **0%** | **1%** | **2%** | **3%** | **4%** | **5%** | **6%** |
| | **0%** | | | | | | | |
| | **10%** | | | | | | | |
| | **20%** | | | | | | | |
| | **30%** | | | | | | | |
| | **40%** | | | | | | | |
| | **50%** | | | | | | | |

Each cell in the table represents a specific scenario. A total of 50 simulation runs were performed for each of these scenarios (cells) in Table 7-16.

Each combination of time management and investment rate improvements represents a specific scenario. To incorporate the effect of variability in the parameters, 50 simulation runs were performed for each of these scenarios with 30% variability included in system parameters. A total of 50 simulation outputs were thus created for the years 1980 to 2030 for each of the combinations. To obtain a convenient measure of comparing the different scenarios, the average of these trends was calculated by obtaining the average value of the trend for each of the scenarios from the years 2010 to 2030. The calculation resulted in a single value.

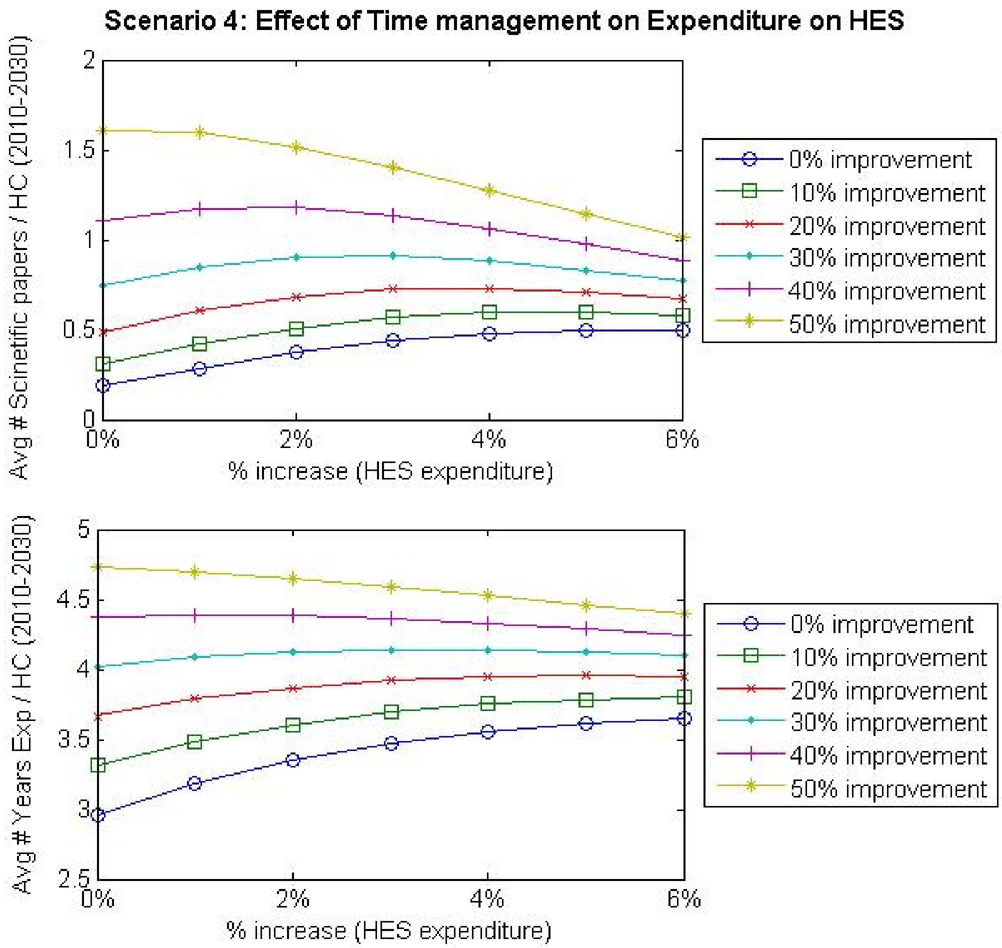



**Figure 7-38: Scenario 4: Papers Produced per Headcount on the HES**

The figure depicting the average number of scientific publications per headcount in the system clearly illustrates that an increase in funding cease to contribute to the productivity of the workers in the case of a more time efficient work force, i.e. a 50% improvement in time management.

This phenomenon can be explained better by referring to the average experience per staff member in the system. For a workforce with 50% improvement in time management, the experience per headcount for a 0% increase in HES investment is actually higher than for the 6% increase in HES investment in a year. This can be attributed to the fact that the effect the student-to-staff rate has on the percentage time spent on R&D becomes less important as R&D staff have improved time management skills.

This phenomenon is only visible for higher levels of time management improvements. For lower percentages, e.g. 20%, the high increase (6%) per year might still contribute to a higher level of productivity than at the 0% increase per annum.

It can therefore be concluded that a combined improvement in time management as well as an increase in the system's human resources could both have a positive effect as well as pose a very cost-effective way of improving the output produced per headcount in the system.

When considering the knowledge production rate, it becomes quite evident that higher investment increases together with an improvement in time management yields the best results.

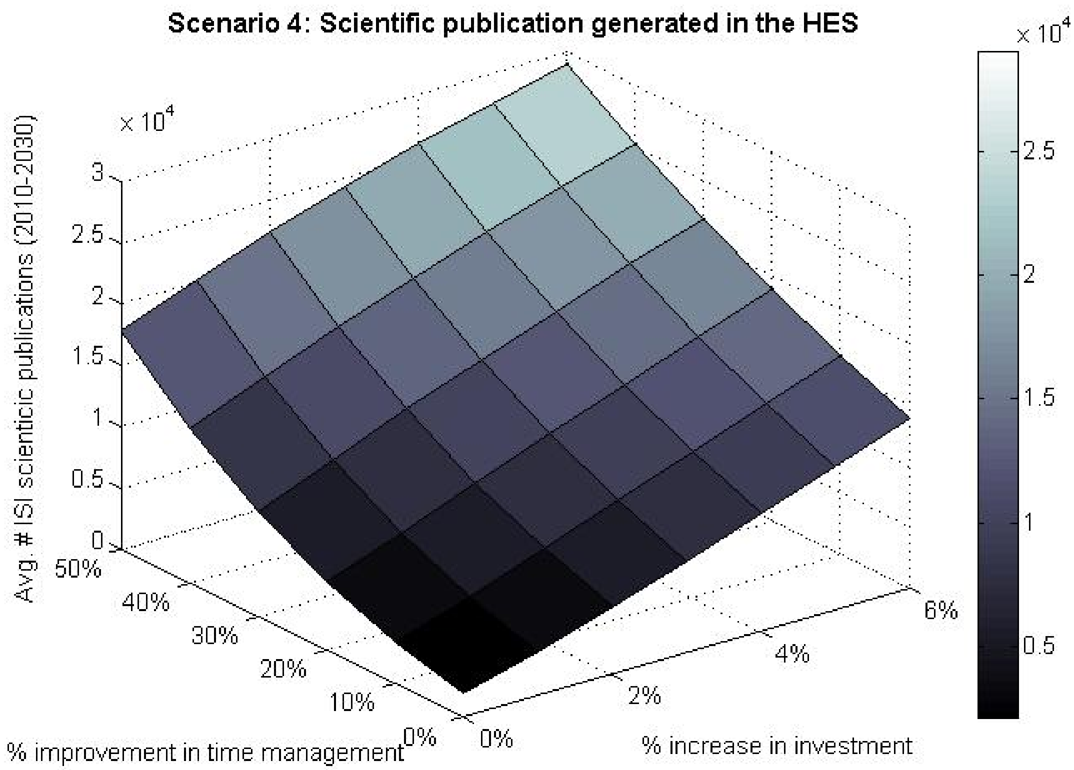



**Figure 7-39: Scenario 4: ISI Scientific Publications Generated in the HES**

The colour coding in Figure 7-39 indicates that roughly similar results can be obtained for a system where a 6% increase in staff per year versus a 0% increase in staff and a 50% improvement in time management in terms of the average number of papers produced in the HES.

We can therefore conclude that improved time management of researchers in the system could prove more effective than merely increasing funding in the system. This would also pose an extremely cost effective solution to the current problems faced in the system.

## 7.6 Chapter summary

In this chapter, the conceptual model developed in Chapter 4 was applied to the South African HES.

Data was gathered from different sources. Secondary data was gathered from the HEMIS database as well as the R&D surveys from 1977 to 2003. The data gathered was used to both populate the model as well as to estimate parameters in the model.

The parameters for the production of knowledge as well as the rate of the absorption of new knowledge were estimated statistically. The model was tested rigorously for spuriousness in the modelled relationship.

Further model runs and sensitivity analyses were also conducted on the model followed by a range of tests conducted on the model. The outcome of these tests indicated that although the model has numerical sensitivity to uncertainty in assumptions, it does not seem to have policy or behaviour sensitivity to uncertainty in starting values for stocks and parameter values.

The scenarios tested on the model concluded that should the system continue with the current trend of an increasing student-to-staff relationship and the level of time management, the system will continue to loose R&D capacity and the current level of R&D output generation will decay.

The scenario tests conducted to analyse the cost of delaying investment indicated that as the system is allowed to decay and loose capacity, the costs of rebuilding the system will increase.

A policy was tested on the system to investigate the possible introduction of science chairs to the system for the preservation and development of centres of excellence in the system. It was found that although the average level of R&D knowledge could decay, the establishment of science chairs could provide a way of establishing centres of expertise in the system. This however would only be successful should there be an investment in increasing the current academic and research staff stock in the system.

A possibly cost effective solution to delay the decay of the system's R&D capacity was found to be the implementation of an improvement in time management in academic and research staff. This is however only a temporary solution to the mounting student numbers and the resulting decreasing percentage of time that academic and research staff spend on R&D in the HES.

This chapter thus developed a system dynamics model of R&D in the South African HES. The following chapter depicts the application of the conceptual model on R&D activities in the South African public sector.

# 8 PUBLIC SECTOR MODEL

In this chapter, the conceptual model developed in Chapter 5 is applied to the South African public sector. A similar model structure, employing the dynamic model derived from theory, is used. The quantification of the stocks and flows is however chosen to be descriptive of the sector's specific characteristics.

Time series data of R&D inputs into this sector was gathered from R&D surveys based on the Frascati manual for the years 1977 to 2003. Although numerous issues might exist in terms of the data gathered over the years (especially with the data gathered from the Frascati surveys - see section **Error! Reference source not found.** for a detailed discussion), it is however by far the most accurate records available. Although noting the issues surrounding the accuracy and usefulness of the data and model, the data available is considered useful for the purposes of this study.

Data on patents registered by South Africans in South Africa was obtained from the South African Patent journal published by the South African patent office. Furthermore, data on the scientific output generated in the sector was gathered from the ISI web of science.

The actual data and data tables gathered is presented in Appendix B, while the data as well as the conclusions drawn from data trends are discussed in this chapter. The following section provides a brief overview of R&D organisations in the South African public sector.

## 8.1 Definition of the Public sector

The definition of the Public sector in this thesis follows the same definition as described in the Frascati survey. The reason for this is that this thesis makes use of the data gathered from the Frascati survey. The broad definition of the Public sector (called Government sector in the survey) is *(OECD, 2002 a)*[1]:

- *All departments, offices and other bodies which furnish, but normally do not sell to the community, those common services, other than higher education, which cannot otherwise be conveniently and economically provided, as well as those that administer the state and the economic and social policy of the community. (Public enterprises are included in the business enterprise sector.)*

- *NPIs controlled and mainly financed by government, but not administered by the higher education sector."*

The following section provides a brief over view of the biggest organizations surveyed in the Public sector in South Africa

[1] See The Frascati Manual (OECD, 2002a) for a more detailed description of the followed in the R&D surveys to categorise organisations into sectors.

## 8.1 Overview of the Sector

There are eight ***Science Councils*** (SC) in South Africa (CENIS, 1999: 149):

- Council of Scientific and Industrial Research (CSIR)
- Human Sciences Research Council (HSRC)
- Medical Research Council (MRC)
- Mineral Technology Council (MINTEK)
- South African Bureau of Standards (SABS)
- Council for Geosciences (CGS)
- Agricultural Research Council (ARC); and
- National Research Foundation (NRF), which is the funding agency of the country.

There are four state funded National Research Institutes (***National Facilities***) in South Africa, namely the South African Astronomical Observatory (SAAO), Hartebeeshoek Radio Astronomy Observatory (HartRAO), National Accelerator Centre, and the JLB Smith Institute for Inchtyology (Mouton, 2001:7).

There are a number of ***government departmental in-house research institutes*** and centres, including the National Institute of Virology (Deptment of Health), Weather Bureau, National Botanical Institute (Department of Environmental Affairs and Tourism) and the National Department for Curriculum Research and Development (Department of Education) (Mouton, 2001:7).

The following section briefly discusses the data gathered from Frascati R&D surveys, the ISI web of science and the South African patent office. The quantification of the stocks developed for the conceptual model is also described and explained.

## 8.2 Data Gathering and Analysis

### 8.2.1 R&D expenditure

The financial expenditure data was gathered from the South African R&D surveys. Table 8-1 lists the data gathered regarding R&D expenditure in the public sector from R&D surveys. (See Appendix B, section **Error! Reference source not found.** for actual data and description of the survey methodology).

**Table 8-1: Data Gathered for R&D Expenditure in the Public Sector**

| Data Input | Source | Table |
|---|---|---|
| Source funding from business sector to public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Source funding from HES to the public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Own funds public sector (1980-2003) | R&D survey (1977-2003) | **Error! Reference** |

| | | |
|---|---|---|
| | | **source not found.** |
| Percentage R&D expenditure (capital) in public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure (human resources) in public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| - Expenditure on researchers<br>- Expenditure on technicians<br>- Expenditure on support staff | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on basic R&D in public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on applied R&D in public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on experimental development in public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Investment in capital stock in public sector | R&D survey (1977-2003) | **Error! Reference source not found.** |

Figure 8-1 is a graphical representation of the distribution of R&D expenditure in the public sector. R&D expenditure is divided into three main categories, namely human resources, capital investment and running costs.

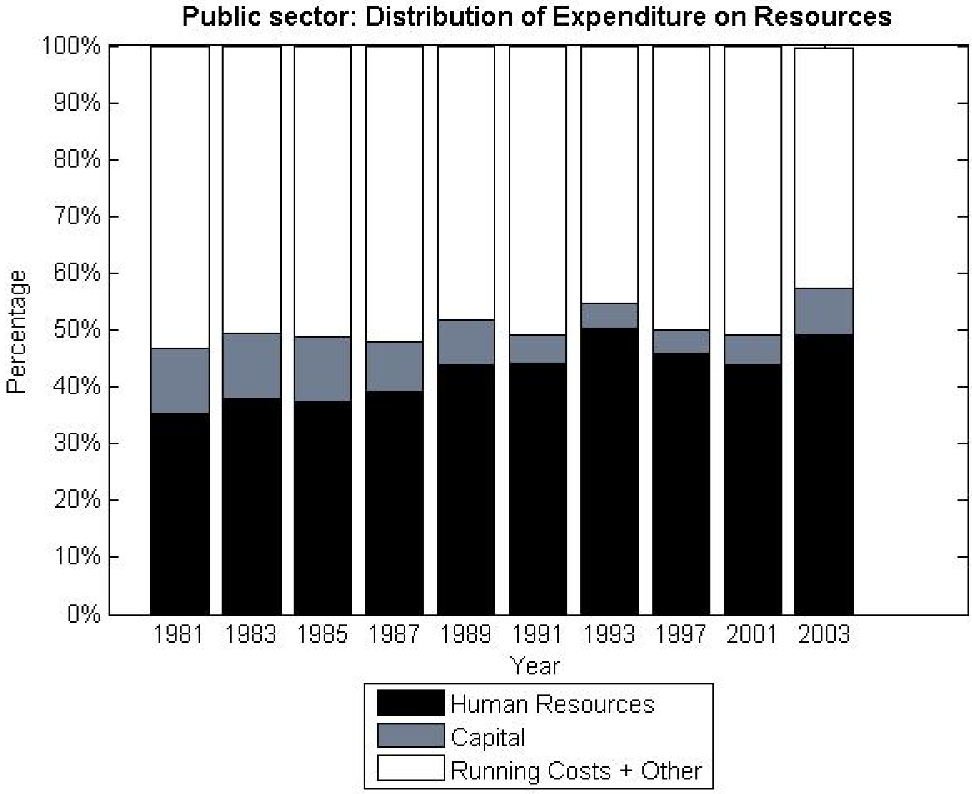



**Figure 8-1 Distribution of Expenditure in the Public sector**

The distribution of the expenditure clearly indicates that a relatively small percentage of funding is directed towards capital resources. For the years 1977 to 2003, an average of approximately 7.76% (standard deviation 3.11%) of the total expenditure was directed towards capital. The percentage has decreased from roughly 11 % in 1981 to approximately 5% in 2003. The data available also does not provide much detail in terms of the type of investment to different fields of science or the type of capital resources. Land and buildings are included in the investment data. We can therefore conclude that a relatively small percentage of R&D expenditure is directed towards investment in capital resources.

The calculation of the percentage of R&D expenditure on labour in the public sector seems to be a relatively constant percentage of approximately 43% of the total expenditure in the system. The average of the percentage for the years 1977 to 2003 is 42.58% (standard deviation of 6.27%). The calculations therefore indicate human resources have been one of the main sources of expenditure on R&D in the public sector.

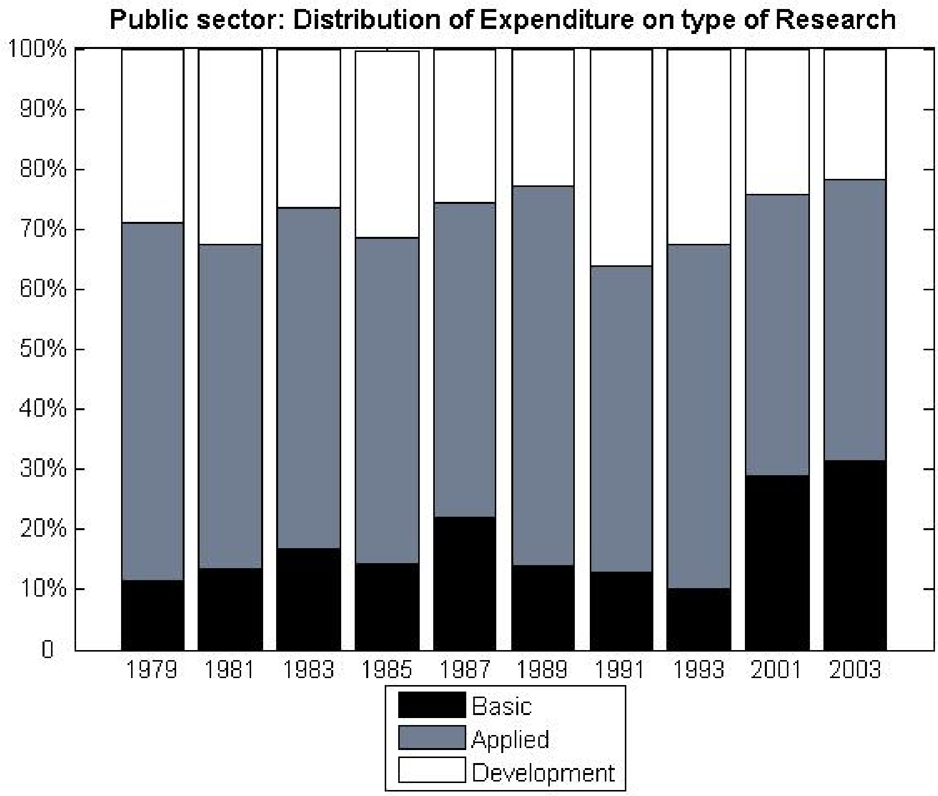



**Figure 8-2: Expenditure on Type of Research in the Public Sector**

The public sector focuses mainly on applied research, with a substantial amount of research being done on experimental development. Over the period 1979 to 2003, an average of roughly 55% of R&D expenditure in the sector was directed towards applied research, with an average of roughly 28% directed towards experimental development over the period 1979 to 2003.

The following table summarises the analysis of R&D expenditure in the South African public sector.

**Table 8-2: Conclusions from HES Expenditure Data Gathered**

| Parameter | Average for 1977 to 2003 | Standard Deviation |
|---|---|---|
| % R&D expenditure (capital) in HES | 7.76% | 3.31% |
| % R&D expenditure (human resources) in HES | 42.58% | 6.1% |
| Expenditure on Researchers<br>Expenditure on Technicians<br>Expenditure on Support staff | 56.34%<br>26.87%<br>16.76% | 8.8%<br>3.86%<br>10.04% |
| Percentage expenditure on basic research<br>Percentage expenditure on applied research<br>Percentage expenditure on experimental development | 15.87%<br>54.36%<br>28.38% | 6.04%<br>5.5%<br>4.25% |

Except for the NRF, science councils receive core funding from three sources, namely contract income on the basis of 'full cost recovery for services', funding from applications to the Innovation Fund on an open competition basis as well as a part of the parliamentary grant for core funding (Marais, 1999:106).

In April 1988, government adopted the system 'Framework Autonomy and Base Line funding' for the management of science councils. Government subsidies were fixed to force councils to secure funding from clients in the public or private sectors. This system was specifically enforced to increase linkages between councils and industry (Kaplan, 1995:8).

The policy and framework of framework autonomy was designed to enhance the execution of R&D in national interest and to undertake contract research. This resulted in greater degrees of autonomy were granted to public entities as well as a decrease in public funding on a range of institutions. The frame work autonomy baseline funding policy (Marais, 1999):

- gave highest possible autonomy in terms of matters of internal organisation
- made applied and problem oriented research self-funding through contract research; and
- made provision for the cost of basic research to be borne by the state.

There were however a number of negative consequences of the culture of research within the councils. Research portfolios within councils became more market driven, while inevitably less attention was given to socio-economic and development goals. Collaboration between institutes declined and competition became the order of the day (CENIS, 2000: 35). More recently, this shift towards a more market driven model came under fire.

It is thus hypothesised that as the percentage contract research funding received by organisations in the public sector increases, the focus shifts away from the creation of scientific output, such as scientific publications and patents that will remain in the name of organisations in the public sector.

Figure 8-3 depicts an increasing trend in the percentage of R&D expenditure sourced from the private sector.

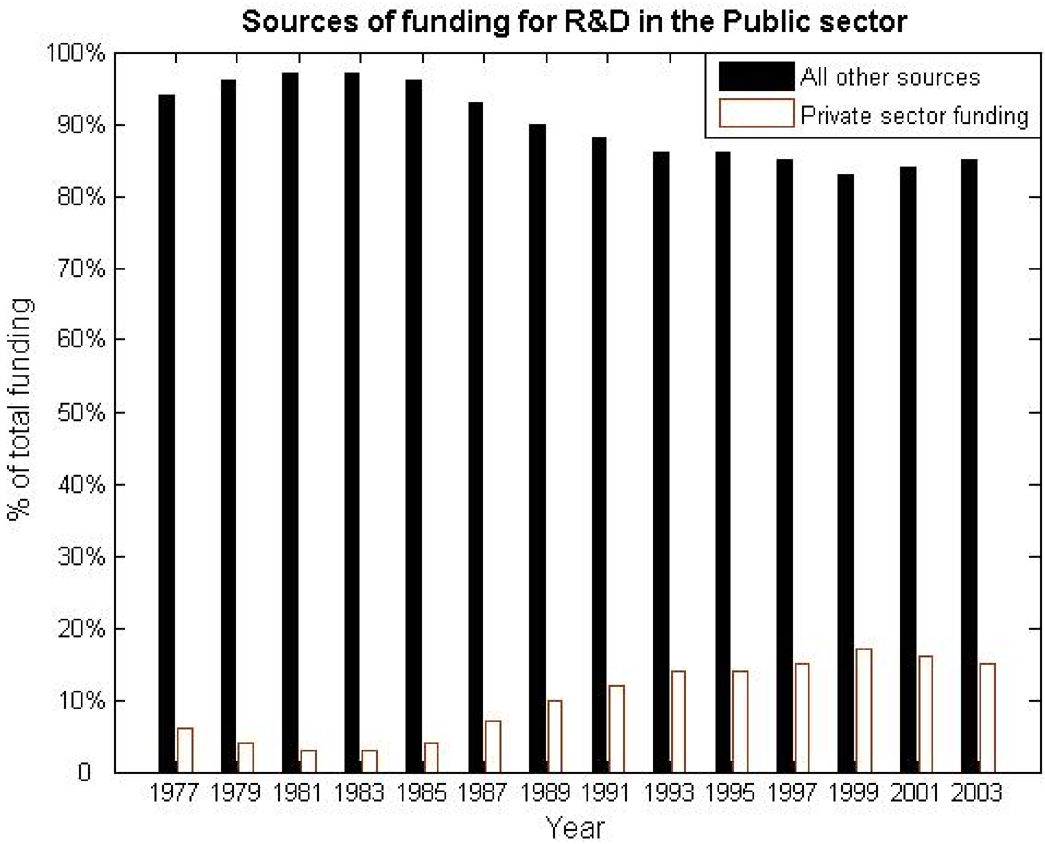


**Figure 8-3: Increasing Trend in Funding from the Private Sector**

A rough approximation is made that all funding flowing from the private sector to the public sector is directed towards contract funding and that all other types of funding flowing into the sector is thus considered to be non-contract funding.

This trend depicts increased contract income and funding for R&D in the public sector. This phenomenon is in line with the automatic expectation from the implementation of the 'Framework Autonomy and Base Line funding' of 1988. This policy was implemented for the management of the science councils in a bid to gradually decrease government funding, thus forcing them to earn contract income from the industry.

### 8.2.2 Human resources in the public sector

**Table 8-3: Data Gathering for Human Resources in the Public Sector**

| Data Input | Source | Table |
|---|---|---|
| Total human resources stock (1980-2003) | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Fulltime equivalent researchers | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage time spent on R%D | To be computed | **Error! Reference source not found.** |

Figure 8-4 is a graphical representation of human resources data gathered from the Frascati manuals.

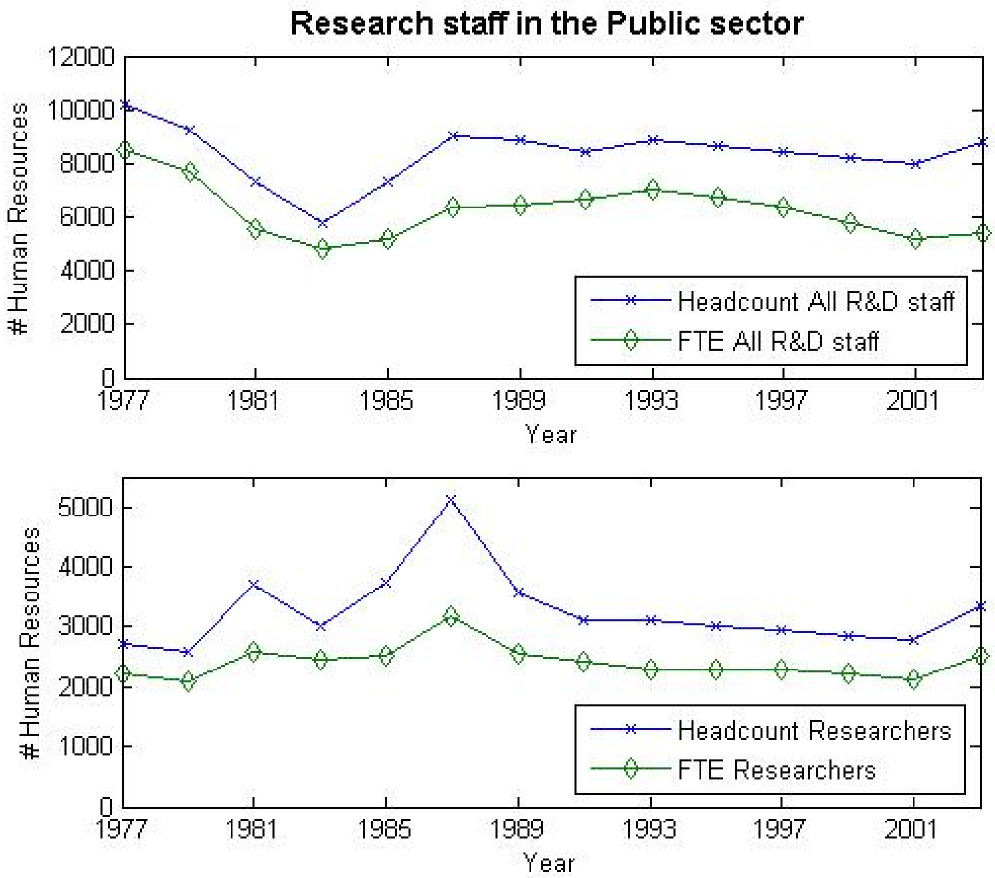



**Figure 8-4:** **Data Gathered for Human Resources in the Public Sector**

Both the above graphs present the headcount as well as fulltime equivalent human resources. The first graph represents data for the total research staff and the fulltime equivalent of all human resources involved in R&D activities in the sector.

To obtain a more complete picture of the importance of the role that the different types of human resources play in the sector, the average expenditure spent on the human resources groups, the headcount and the FTE is analysed.

**Table 8-4:** **Distribution of Human Resources in the Public Sector in South Africa**

| | Expenditure | | Headcount | | Fulltime Equivalent | |
|---|---|---|---|---|---|---|
| | Average | Standard Deviation | Average | Standard Deviation | Average | Standard Deviation |
| **Researcher** | 56% | 9% | 41% | 11% | 39% | 8% |
| **Technical** | 27% | 4% | 27% | 4% | 29% | 5% |
| **Support** | 17% | 11% | 32% | 13% | 32% | 12% |

The information in Table 8-4 can be depicted in the following pie charts.

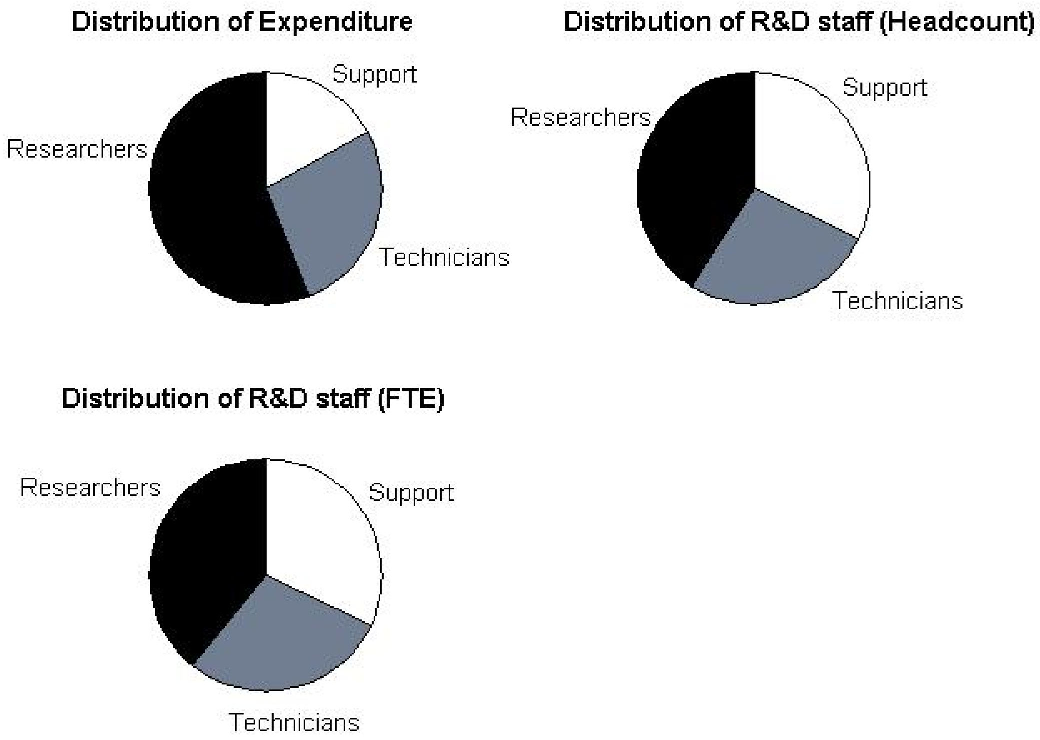



**Figure 8-5 Distribution of expenditure on Human Resources**

From evidence provided in Figure 8-5, it can be concluded that technical personnel and support personnel comprises a large portion of expenditure on human resources in the public sector. The same can be said for the recorded fulltime equivalent R&D staff employed in the system. Support and technical staff will consequently not be excluded from the analysis. We can however see that most of the R&D expenditure on HR is directed towards researchers, who constitute the largest percentage of the headcount as well as the fulltime equivalent staff in the system.

Since the Frascati surveys were conducted biannually, the data points in the time series process is only available for every second year, while the data on the R&D output generated in the system is available yearly. The evidence obtained in Figure 8-5 concludes that all three groupings of R&D staff should be included in the analysis. A definite trend is depicted in the graphical representation of the human resources in Figure 8-4. For this reason, the data is thus extrapolated to be compatible with the R&D output which is available for every year.

The method used to analyse and calculate the percentage time spent by personnel on R&D is as follows: the fulltime equivalent staff is divided by the headcount personnel as reported in the Frascati based R&D Surveys. The result then is used as the average percentage time that R&D personnel reportedly spend on R&D activities:

- percentage time all staff = FTE staff (survey)/HC staff (survey); and
- percentage time researchers = FTE researchers (survey data) per HC researchers (survey).

The percentage time spent by personnel in the public sector as an average for the years 1977 to 2003 is 76% (deviation 6.49%). The average time spent by researchers in the system is in a similar region at 74.33% (deviation 6.59). The data can be tabulated as follows:

**Table 8-5: Conclusions from Public Sector Human Resources Data Gathered**

| Parameter | Average for 1977 to 2003 | Standard Deviation |
|---|---|---|
| Percentage time spent on R%D (all R&D staff) | 76% | 6.49 |
| Percentage time spent on R%D (researchers) | 74.3% | 6.59 |

### 8.2.3 Data gathered on the development of knowledge

We have already determined that apart from basic research, the public sector performs a large percentage applied and developmental research. The sector's R&D outputs will therefore be insufficiently represented when only considering scientific publications generated in the sector.

*The measurement of basic and applied research in the public sector*

The following is a graphical representation of the respondents' feedback in the Delphi study on the applicability of scientific output as a proxy for basic and applied research output in the South African public Sector (see section **Error! Reference source not found.**).

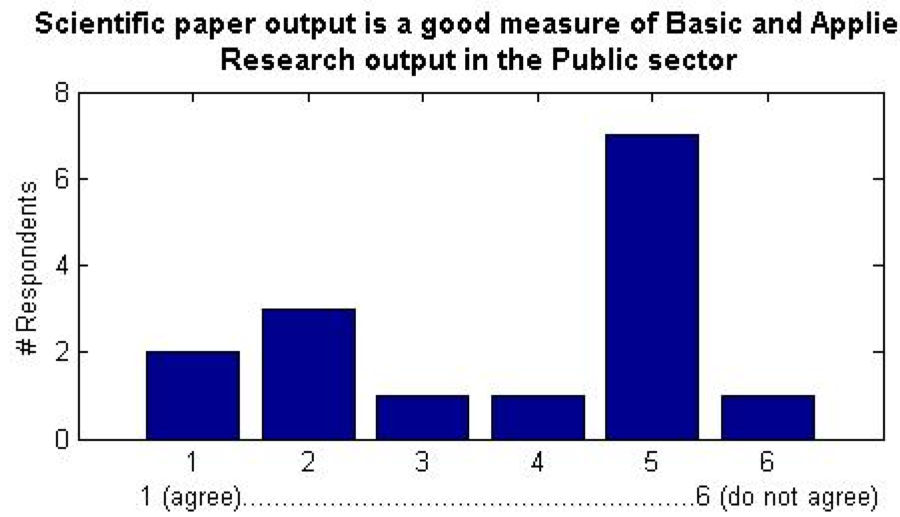



**Figure 8-6: Measurement of Basic and Applied Research Output**

The mode and median for the feedback gained from the expert panel was five, indicating that the aggregated expert opinion is that scientific publication output is not an adequate measure of basic and applied research output in the public sector.

It is however interesting that a number of respondents view this measure as an appropriate means of measuring basic and applied research output in this sector. Five of the 14 respondents responded with a ranking of one or two, indicating that it is a good measure to use. Due to a lack of any better measure available, it is therefore decided to continue the analysis by using scientific publication output as a indicator.

The obvious shortcomings of following this approach must however be kept in mind when interpreting the results gained from the model simulation runs.

**The measurement of experimental development in the Public sector**
The following is a graphical representation of the respondents' feedback in the Delphi study on the applicability of patent counts as an indicator for experimental development output in the South African public sector (see section **Error! Reference source not found.**).

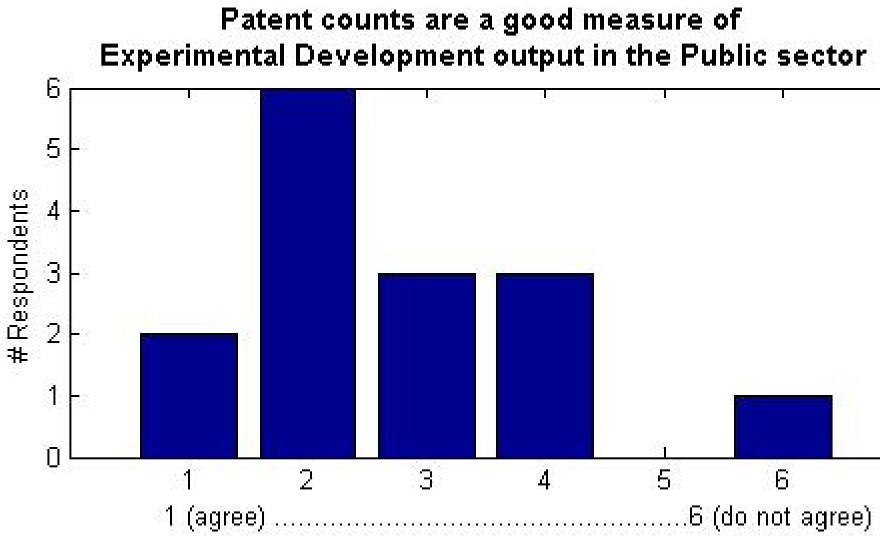



**Figure 8-7 Measurement of Experimental Development in the Public Sector**

The feedback gathered from the respondent's yield that patents proof to be a relatively good choice of measurement for experimental development output generated in the public sector. The responses reveals that the mode is two, thus indicating that the respondents view this measure as a valid proxy for measuring experimental development output in the public sector. It is also established that from the 12 respondents, only four ranked above three, which indicates that patent output is a relatively good measure of experimental development output in the South African public sector. Naturally, this approach has its weaknesses, which is also reflected in the average rating of 2.73 by the expert panel.

The above discussion therefore concludes that the following proxies can be used to measure different types of research and the corresponding output in the public sector:

- the proxy used for R&D outputs from basic, strategic and applied research performed in this sector is the amount of scientific publications produced in the public sector; and
- the proxy used for R&D outputs from developmental research performed in this sector is the amount of patents granted to organisations in the public sector.

**Table 8-6: Data sources for the measurement of knowledge in the Public sector**

| Data Input | Source |
|---|---|
| Sector knowledge creation (scientific papers) (1980-2003) | ISI web of science, South African patent office |
| Knowledge depreciation rate (citation curve) | ISI web of science (1977-2003) |
| Sector knowledge creation (patents) (1980-2003) | SAPTO |
| Knowledge depreciation rate (citation curve) | To be estimated |

#### 8.2.3.1 R&D output from basic and applied research

The following is a graphical representation of the scientific output generated in the public sector in South Africa.

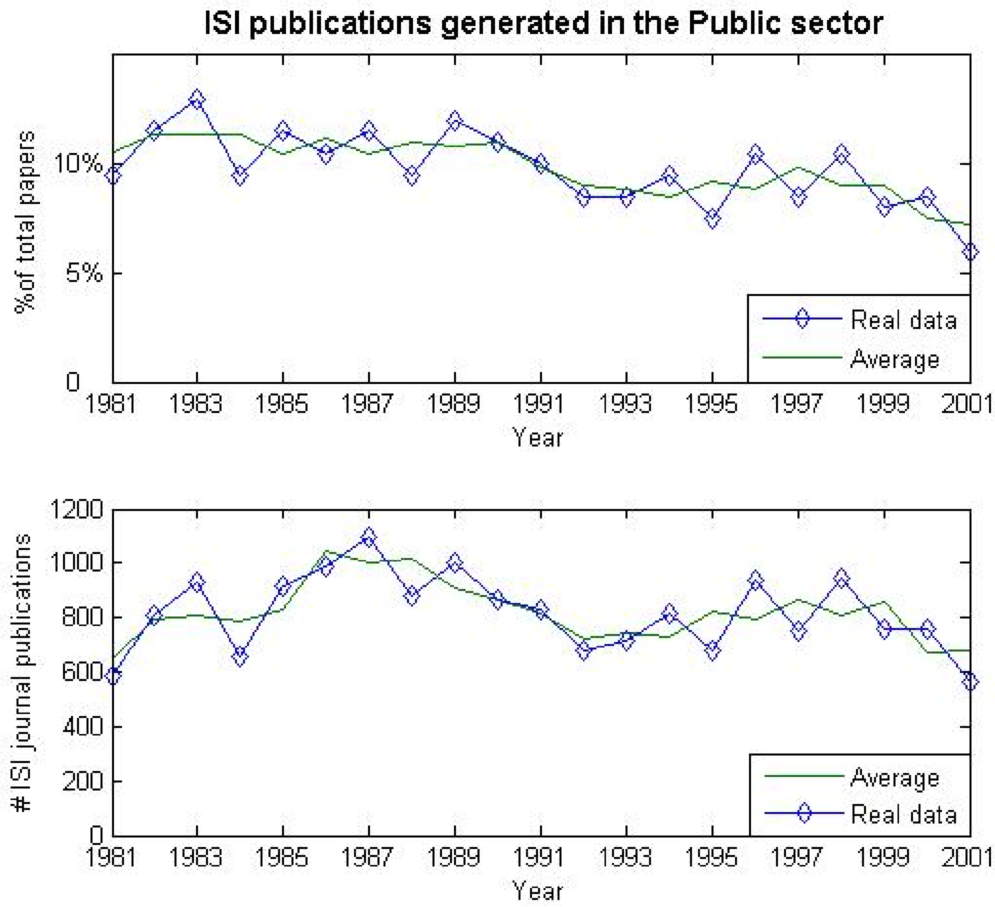



**Figure 8-8: Scientific Output Generated in the South African Public Sector**

Figure 8-8 depicts the scientific output generated in the sector in two different graphs. The first reveals the percentage of the outputs generated in the sector as a percentage of scientific output generated in South Africa as a whole. The second shows a trend in which the scientific output generated in the sector is depicted in the number of scientific journal articles generated from the sector and published in ISI journals.

The trend in Figure 8-8 that the scientific output created in the public sector thus reveals a gradual decline starting in the late 1980s.

#### 8.2.3.2 R&D outputs from developmental research

The second proxy used for the generation of knowledge in the public sector is the patents registered by organisations in the public sector.

The USPTO data reflects a negligible amount of patents originating from the South African public sector. This result forces the author to consider the patents registered at the South African patent office as a proxy.

Unfortunately, a general state of disarray exists at the South African patent office, with no database or account of patents granted being accessible at a central location. This was one of the main factors impeding the analysis of the patents granted to the public sector in South Africa. Finding patent data for the public sector proved difficult and time consuming.

Patents journals are published on a monthly basis to report the most recent patents granted at the South African patent office. Each patent journal from 1985 to 2004 thus had to be analysed individually. All patent entries in the journals were scrutinised for a South African (ZA)[2] country of origin address. Once obtained, the name of the assignee was checked. The patent was subsequently assigned to one of three categories: HES, public sector or private sector, on an assignee name basis.

The following is a graphical representation of the number of patents granted to organisations in the public sector at the South African patent office from 1985 to 2004.

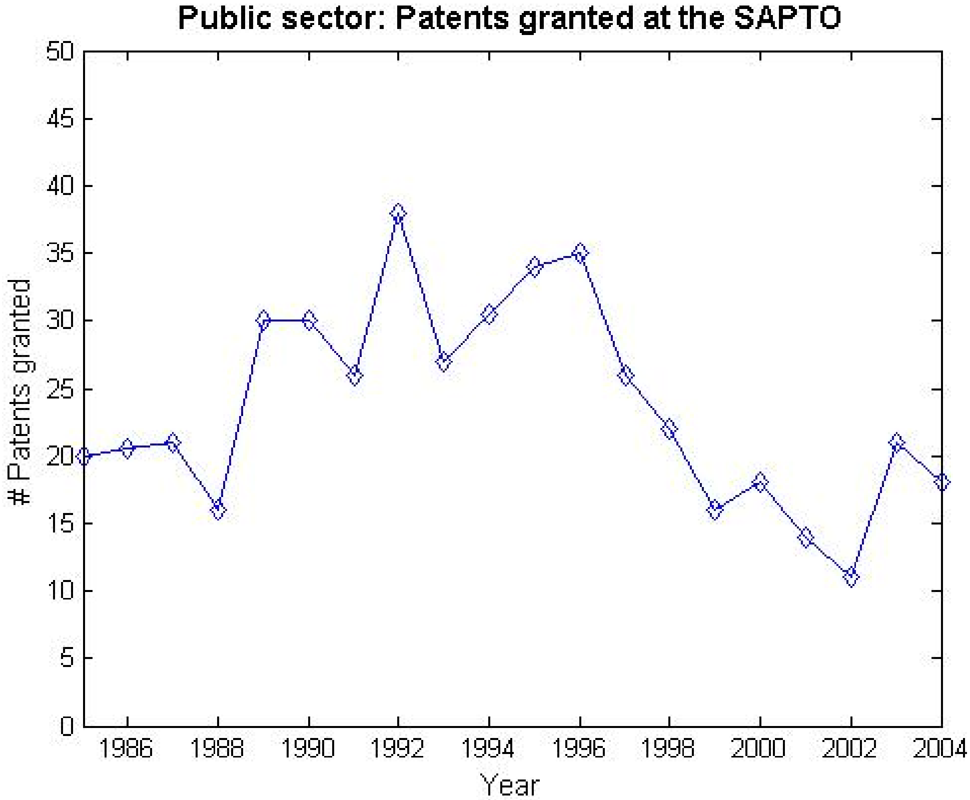



**Figure 8-9** **Patents Granted to Organisations in the Public Sector (SAPTO)**

Data obtained from the patent journals from the South African patent office (1985 to 2004) indicates that the South African public sector revealed a decreasing trend in patents granted over the past decade.

### 8.2.4 Data gathered on the absorption of knowledge

**Table 8-7: Sources of Data for the Measurement of the Absorption of Knowledge**

| Data Input | Source |
|---|---|

[2] It is acknowledged that a measure of uncertainty exists in considering the priority country as a basis of finding the country that the inventor resides in. After discussions with a number of patent attorneys, it was concluded that the uncertainty is negligible and that a good approximation of patents granted to South Africans could be achieved by following this method.

| | |
|---|---|
| Rate of knowledge absorption (references) | ISI Web of Science |
| Initialisation of absorbed knowledge stock in 1980 | To be estimated |
| Depreciation of acquired knowledge stock | To be estimated |
| Initial acquired knowledge stock in 1980 | To be estimated |

Since papers are used as a measure of the development of new knowledge in the sector, the absorption of knowledge is also measured by the rate at which scientists reads, interprets and uses knowledge created in the external environment to perform R&D.

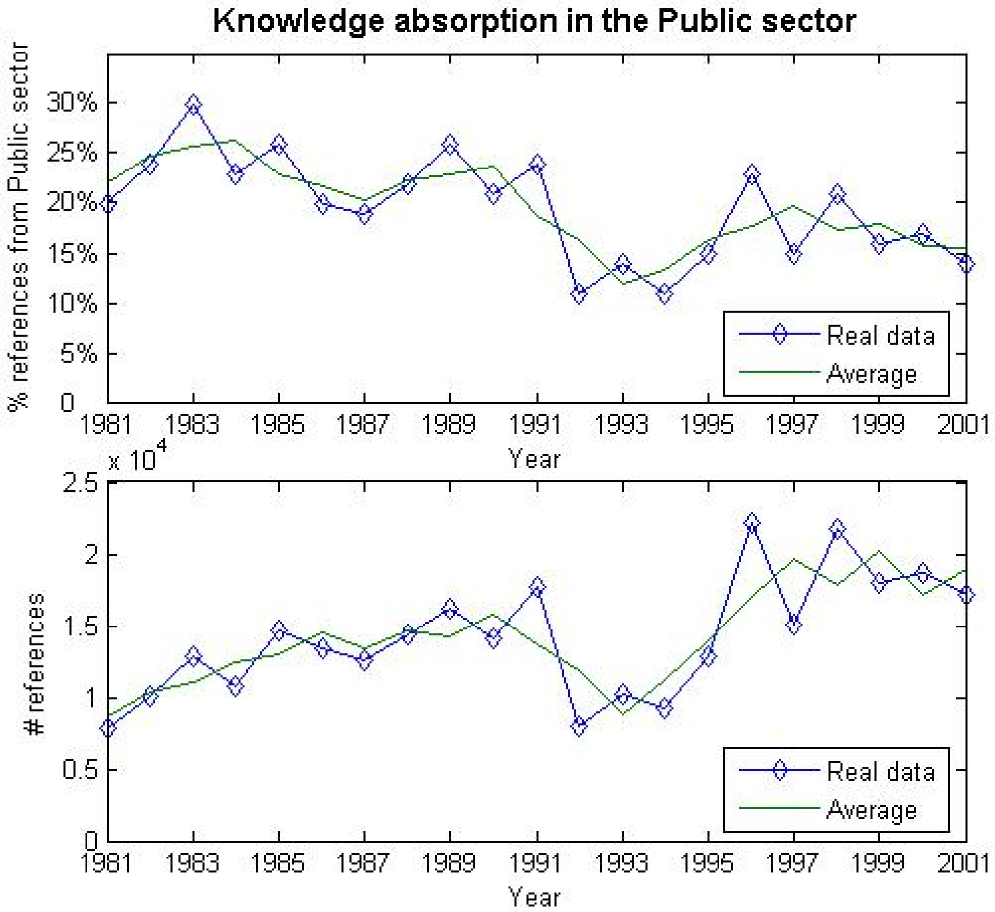



**Figure 8-10: References Made to Knowledge Created in an External Environment**

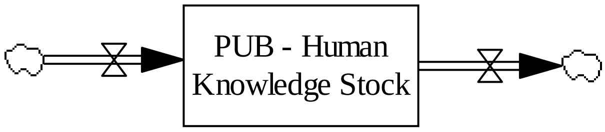
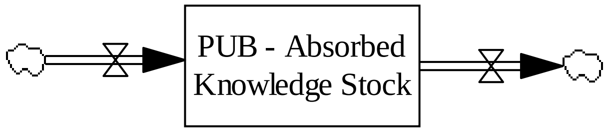
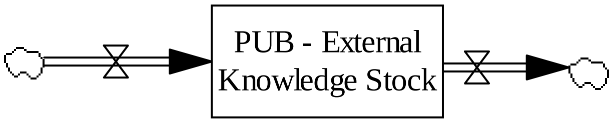
As the South African patent office does not examine patents before they are granted, no references to prior art are recorded in the patent files. No data is consequently available for knowledge absorption, which leads to the creation of new ideas, resulting in patents in the public sector.

## 8.3 Quantification of Stocks in the Public Sector

The following table describes the unit of measurement and quantifications of stocks for the public sector:

**Table 8-8: Stocks for the Public Sector Model**

| Stock | Quantification |
|---|---|

| | |
|---|---|
|   | FTE – Researchers employed during the year<br>Unit: FTE research staff |
|   | Cumulative years experience of FTE researchers<br>Unit: Year |
|   | R&D output generated in HIS<br>Unit: Patents and Papers |
|   | Stock of absorbed knowledge is measured by counting the amount of foreign papers cited by scientists in the system<br>Unit: Papers |
|   | The stock of external knowledge is the amount of scientific publications or patents in the external<br>Units: Papers and Patents |

The following section describes the data gathered and the fundamental R&D inputs to the public sector.

## 8.4 Model Development and Calibration

**See Appendix G for the stock and flow diagram for the Public sector model**

### 8.4.1 Human resources subsystem

This section describes the population of the conceptual model with the data gathered. The first subsystem developed is the human resources subsystem.

The Frascati survey data revealed that the recorded amount of R&D staff employed in 1981 in South Africa was 7 352, from which an even distribution of people for all age cohorts is assumed. The initial values for the cohorts can therefore be calculated as follows:

**Table 8-9: Initialisation of Age Cohorts**

| Age | Years | Percentage | Starting values |
|---|---|---|---|
| 25-40 | 15 | 15/35 = 42.86% | 3152 |
| 41-50 | 10 | 10//35 = 28.57% | 2100 |
| 51-60 | 10 | 10/35 = 28.57% | 2100 |
| Total | 35 | 35/35 = 100.00% | 7352 |

The following table summarises the assumptions made in the development of the human resources subsystem in the public sector:

**Table 8-10: Parameters for Estimation in the Public Sector Model**

| Parameter | Estimated Value |
|---|---|
| Average retirement age | 65 years |
| Recruitment distribution between cohorts:<br>• Young<br>• Experienced<br>• Mature | <br>77%<br>11%<br>11% |
| Natural attrition percentage of cohorts:<br>• Young<br>• Experienced<br>• Mature | <br>5%<br>5%<br>5% |
| Initial values for the HR stocks (1980)<br>• young<br>• experienced<br>• mature | Total: 7352<br>3152<br>2100<br>2100 |
| Decay rate of knowledge stocks and experience | 10% per year |
| Average time spent on R&D | 0.74 (10% variation) |

The experience stock employs the co-flow structure as discussed in the development of the conceptual model diagram in Chapter 4. Experience gained from doing research is measured in terms of the FTE researchers working in the system during a specific time period.

Initially, an experiment was conducted on the model to test its behaviour in the development of experience in R&D. All experience stocks were initialised with zero values. The target academic and research staff in the system was set to a constant value of 7 352. The percentage time spent by researchers on R&D is set at 74%.

An examination of the average level of experience possessed by the different age cohorts of academic and research staff as the system reaches equilibrium yields an interesting observation. Figure 8-11 depicts the output from the model for the simulation run for a constant average of 75% time spent on R&D.

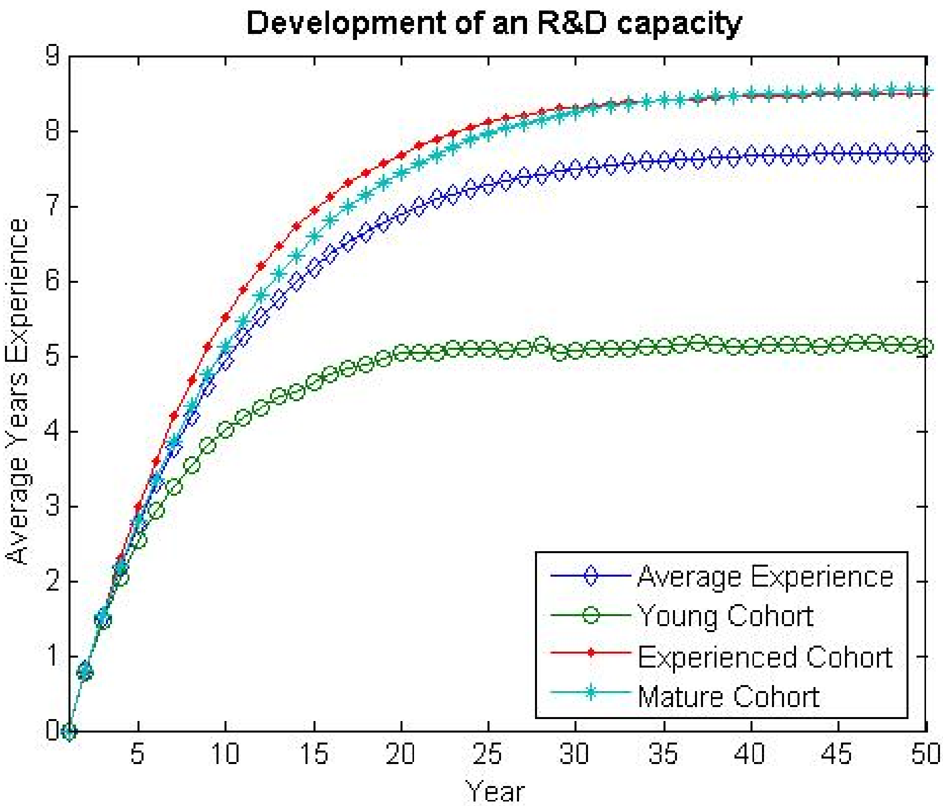



**Figure 8-11 The Development of an R&D capacity (age cohorts)**

Figure 8-11 reflects the expected trend that young researchers will not have the same capabilities and tacit knowledge of older, more experienced researchers. Interestingly, the equilibrium levels of experience per person approaches the same value for both the experienced and mature researchers stocks. This phenomenon can be explained by the dynamics included in the model that knowledge also decays through 'forgetting' and that for a fixed R&D intensity, the system approaches an equilibrium level where only knowledge gained within a given amount of years remain in the system.

It can therefore be concluded that the system reaches a state of equilibrium after a number of years. It is assumed that these equilibrium values are close enough approximations of the average starting value for experience per person in the cohorts. Using the equilibrium levels, we find values for the initial values of the experience stocks.

**Table 8-11: Initial Values for the Experience Stocks**

| Stock Name | Initial Value |
|---|---|
| Young experience stock (25-39) | 15760 (years) – 3152 with an average of five years experience |
| Experienced experience stock (40-49) | 17850 (years) – 2100 with an average of 8.5 years experience |
| Mature experience stock (50+) | 17850 (years) – 2100 with an average of 8.5 years experience |

### 8.4.2 Absorption of knowledge subsystem

Regression analysis is employed to develop the following model for the absorption of knowledge into the system. The rate at which the system is able to absorb knowledge is calculated by the contribution made from different stocks in the system as well as the external environment. The following expression is formulated for the R&D knowledge absorption rate in the system:

- $R_{Absorption}$ : absorption rate of knowledge in the system
- $S_{R\&Doutput}$ : R&D output stock in the system
- $S_{FTE}$ : stock of fulltime equivalent people in the system
- $S_{World}$ : available external knowledge stock (patents); and
- $S_{HC}$ : headcount personnel employed in the system.

A multiplicative model is developed for the absorption rate per fulltime equivalent person working in the system:

$$\frac{R_{Absorption}}{R^{*}_{Absorption}} = f * (\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutput}} * \frac{S_{FTE}}{S^{*}_{FTE}})^{d} * (\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}})^{e} \quad \textbf{8-1}$$

This expression is linearised by taking the log-linear form:

$$\ln(\frac{R_{Absorption}}{R^{*}_{Absorption}}) = f + d * \ln(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutput}} * \frac{S_{FTE}}{S^{*}_{FTE}}) + e * \ln(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}})$$

**8-2**

The following estimates for the parameters are obtained from the SAS analysis output:

**Table 8-12: SAS Output for the Estimation of Model Parameters**

```
                          Dependent Variable    AbsorbedR

                          Ordinary Least Squares Estimates

              SSE                    0.2953922    DFE                       15
              MSE                      0.01969    Root MSE             0.14033
              SBC                   -14.223913    AIC                -16.895028
              Regress R-Square          0.5317    Total R-Square        0.5317
              Durbin-Watson             3.3536    Pr < DW               0.9979
              Pr > DW                   0.0021
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.
                                                  Standard                  Approx
            Variable         DF      Estimate        Error     t Value    Pr > |t|

            Intercept         1        0.2143       0.0750        2.86      0.0120
            RDfte             1        0.3880       0.1719        2.26      0.0393
            patwsperhc        1        0.1936       0.1211        1.60      0.1308

                        Q and LM Tests for ARCH Disturbances

                  Order            Q     Pr > Q          LM     Pr > LM

                    1         3.2076     0.0733      2.9992     0.0833
                    2         3.7507     0.1533      2.9994     0.2232
                    3         3.8340     0.2800      2.9994     0.3917
                    4         7.5941     0.1076      6.0103     0.1984
                    5        10.4175     0.0642      6.0293     0.3034
                    6        13.7073     0.0331      6.3609     0.3840
                    7        15.7191     0.0278      6.8765     0.4418
                    8        15.7699     0.0458      8.3467     0.4004
                    9        15.8418     0.0703     10.2484     0.3308
                   10        15.8851     0.1030     13.4042     0.2019
```

```
                       11          16.1797     0.1346       14.5944     0.2018
                       12          16.2023     0.1821       15.1744     0.2320

                                 Maximum Likelihood Estimates

                  SSE                   0.15202524    DFE                       14
                  MSE                      0.01086    Root MSE             0.10421
                  SBC                   -22.691358    AIC               -26.252845
                  Regress R-Square          0.8553    Total R-Square        0.7590
                  Durbin-Watson             1.9361    Pr < DW               0.2412
                  Pr > DW                   0.7588
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                                                     Standard                     Approx
              Variable          DF      Estimate        Error     t Value     Pr > |t|

              Intercept          1        0.1991       0.0350        5.70       <.0001
              RDfte              1        0.3787       0.0819        4.62       0.0004
              patwsperhc         1        0.2187       0.0577        3.79       0.0020
              AR1                1        0.6712       0.1909        3.52       0.0034

                          Autoregressive parameters assumed given.
                                                     Standard                     Approx
              Variable          DF      Estimate        Error     t Value     Pr > |t|

              Intercept          1        0.1991       0.0350        5.70       <.0001
              RDfte              1        0.3787       0.0819        4.62       0.0004
              patwsperhc         1        0.2187       0.0576        3.79       0.0020
```

The following section summarises the statistical analysis conducted to estimate model parameters. Please see appendix D (section **Error! Reference source not found.**) for a detailed account of the statistical analysis on the data.

The Regress R-Square statistic indicates that the model accounts for 54% of the variation of the data in predicting AbsorbedR.

As the first model fitted with zero lag proves to have autocorrelation, an autoregressive model is fitted with lag = 1. The Durban Watson test statistic is used to gauge autocorrelation. The test statistic is 2.1821 with (Pr < DW = 0.2412) > 0.05 and (Pr < DW = 0.7588) < 0.95., which indicates that the model does not have autocorrelation.

A colinearity test conducted on the data indicated that all the condition indexes from the regression model are smaller than the critical value. It can therefore be concluded that no colinearity is present. (For details on the test see paragraph **Error! Reference source not found.**).

The Phillips-Perron test was employed to test for stationarity. All variables included in the model are non-stationary (section **Error! Reference source not found.**). The test proved that the model residual is stationary and that the variables are cointegrated, which implies that the regression is not spurious. We can therefore conclude that the modelled relationship is non-spurious and that we can use the result to develop the model of R&D in the public sector further.

Due to the relative limited number of data points available (20 data points), the heteroscedasticity test is only interpreted up to two time lags. The probability for arch disturbances in the model for lags one and two are larger than 0.05, which reveals that the modelled relationship does not suffer from heteroscedastic errors.

The parameters are estimated as defined in the following expression:

$$\ln\left(\frac{R_{Absorptionr}}{R^{*}_{Absorption}}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutput}} * \frac{S_{FTE}}{S^{*}_{FTE}}\right) + e * \ln\left(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}}\right)$$

**8-3**

The following table summarises the parameter values as well as the variance introduced into the parameter in the model. The variance is the standard error of the model as reported in the SAS output.

**Table 8-13: Estimated Parameter Values for Knowledge Absorption Trend**

| Parameter | Estimate | Variance (s.e.) |
|---|---|---|
| Intercept (f) | 0.1990 | 0.0347 |
| RDFTE (d) | 0.3787 | 0.0812 |
| WSperHC (e) | 0.2189 | 0.0572 |

The model yields the following output for the absorption of knowledge (measured in terms of references made to scientific papers). A 30% variance is introduced in parameters and initial values in the model. This yields the following result for the average and computed standard deviation of model output of 100 simulation runs:

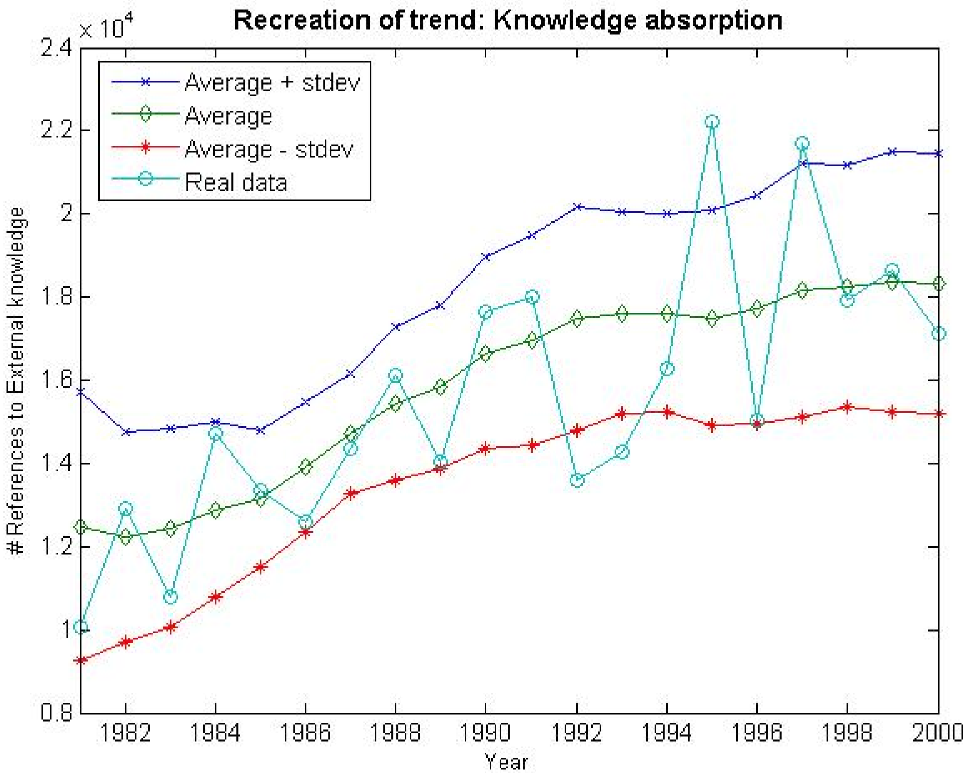



**Figure 8-12: Model Recreation of the Absorption of Knowledge Trend Data**

The coefficient of the determination ($R^2$), the fraction of the variance in the data explained by the model, is computed to be 0.54. This indicates that the average of the model runs explains roughly 54% of the variation in the data.

### 8.4.3 Development of Knowledge

#### 8.4.3.1 Development rate of knowledge (basic and applied knowledge)

Regression analysis was employed to develop the following model for the production of new knowledge output. The rate at which the system is able to produce new knowledge output is calculated by the contribution made from different stocks in the system. The following expression is formulated for the R&D output produced by human resources in the public sector:

- $R_{Paper}$ : rate at which R&D output is generated in the system (papers)
- $S_{FTE}$ : ratio of fulltime equivalent R&D staff in the system
- $S_{Absorbed}$ : absorbed knowledge stock in the system
- $A_{Contract}$ : the ratio of research directed towards contract research; and
- $A_{Basi\&Applied}$ : the ratio of research directed toward basic and applied research.

A multiplicative model is developed for the development rate of papers in the public sector:

$$\frac{R_{Paper}}{R^*_{Paper}} = d*\left(\frac{S_{Absorbed}}{S_{Absorbed}} * \frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{Basic\&Applied}}{A^*_{Bsic\&Applied}}\right)^a \left(\frac{A_{State}}{A^*_{State}}\right)^b \left(\frac{S_{FTE}}{S^*_{FTE}}\right)^c$$

**8-4**

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Paper}}{R^*_{Paper}}\right) = \ln(d) + a*\ln\left(\frac{S_{Absorbed}}{S^*_{Absorbed}} * \frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{Basic\&Applied}}{A^*_{Bsic\&Applied}}\right) + b*\ln\left(\frac{A_{State}}{A^*_{State}}\right) + c*\ln\left(\frac{S_{FTE}}{S^*_{FTE}}\right)$$

**8-5**

This expression is thus developed through the regression analyses with the subsequent estimation of the parameters $a$, $b$, $c$ and $d$. The regression is executed and the following estimates for the parameters are obtained:

**Table 8-14: SAS Output for Development of Basic and Applied Knowledge Output**

```
                        Dependent Variable    RDPapersR

                        Ordinary Least Squares Estimates

        SSE                    0.34819932    DFE                        16
        MSE                       0.02176    Root MSE              0.14752
        SBC                    -12.273779    AIC                -16.256708
        Regress R-Square           0.4791    Total R-Square         0.4791
        Durbin-Watson              1.9593    Pr < DW                0.1850
        Pr > DW                    0.8150
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                               Phillips-Ouliaris
                               Cointegration Test

                        Lags           Rho           Tau

                           1      -22.9280       -4.7653
```

| Variable | DF | Estimate | Standard Error | t Value | Approx Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | 0.6953 | 0.1074 | 6.47 | <.0001 |
| absftetype | 1 | 0.4942 | 0.3316 | 1.49 | 0.1555 |
| FTEtot | 1 | 0.8744 | 0.4561 | 1.92 | 0.0733 |
| Percstate | 1 | 5.1987 | 1.7089 | 3.04 | 0.0078 |

The following section summarises the statistical analysis conducted to estimate model parameters. Please see appendix D (Section **Error! Reference source not found.**) for a detailed account of the statistical analysis on the data.

The **R-Square 0.4791** statistic indicate that the model accounts for 47.9% of the variation of the papers produced in the public sector.

The Durban Watson test statistic was used to gauge autocorrelation use. The statistic is 1.9593 with (Pr < DW = 0.1850 > 0.05 and (Pr < DW = 0.8150) < 0.95, which indicates that the autoregressive model does not have autocorrelation.

Colinearity tests conducted on the data indicated that all the condition indexes from the regression model are much smaller than 30. We can thus conclude that no colinearity is present.

A Chi-square test for the first moment specification indicates that the model does not have heteroscedastic errors. The SPEC option performs a model specification test. The null hypothesis for this test maintains that the errors are homoscedastic, independent of the regressor and that several technical assumptions about the model specification are valid. With Pr = 0.2151, we fail to reject the null hypothesis, which leads to the conclusion that no heteroscedasticity is present in the model.

The Phillips-Perron test was used to gauge stationarity, which indicated that all variables included in the model are non-stationary. After fitting the model, it was tested for stationarity. The test proved that the model residual is stationary and that the variables are cointegrated. This implies that the regression is not spurious. We therefore conclude that the model is non spurious and that we can use the result to develop the model of R&D in the public sector further.

We continue to estimate the parameters for the following expression:

$$\ln\left(\frac{R_{Paper}}{R^*_{Paper}}\right) = \ln(d) + a*\ln\left(\frac{S_{Absorbed}}{S^*_{Absorbed}}*\frac{S_{FTE}}{S^*_{FTE}}*\frac{A_{Basic\&Applied}}{A^*_{Bsic\&Applied}}\right) + b*\ln\left(\frac{A_{State}}{A^*_{State}}\right) + \mathbf{c}*\ln\left(\frac{S_{FTE}}{S^*_{FTE}}\right)$$

**8-6**

The following table summarises the variable values as well as the variance introduced into the parameter in the model. The variance of the parameters is set equal to the standard error as reported in the SAS output.

**Table 8-15: Estimated Parameter Values for Paper Creation Trend in Public Sector**

| Parameter | Estimate | Variance (s.e.) |
|---|---|---|
| Absftetype (a) | 0.4942 | 0.3316 |
| Percstate (b) | 5.1967 | 1.7089 |

| | | |
|---|---|---|
| Ftetot © | 0.8744 | 0.4561 |
| Intercept (d) | 0.6953 | 0.1074 |

Special mention has to be made of the high estimated value for ‘Percstate;, the effect that the percentage funding from the state (non-contract funding) will have on the focus on terms of the creation of R&D outputs, such as papers and patents in the system.

As $A_{State}$ is the variable representing the percentage of the total R&D expenditure in the public sector directed towards non-contract work, it is therefore a variable with a range of $0 < A_{State} < 1$. The initial value is $A^*_{State} = 0.98$, resulting in a ratio with a range of $0 < (\frac{A_{State}}{A^*_{State}}) < 1.02$.

Figure 8-13 is a graphical representation of the effect that the percentage funding intended for non-contract research could have on the public sector’s production of scientific publications.

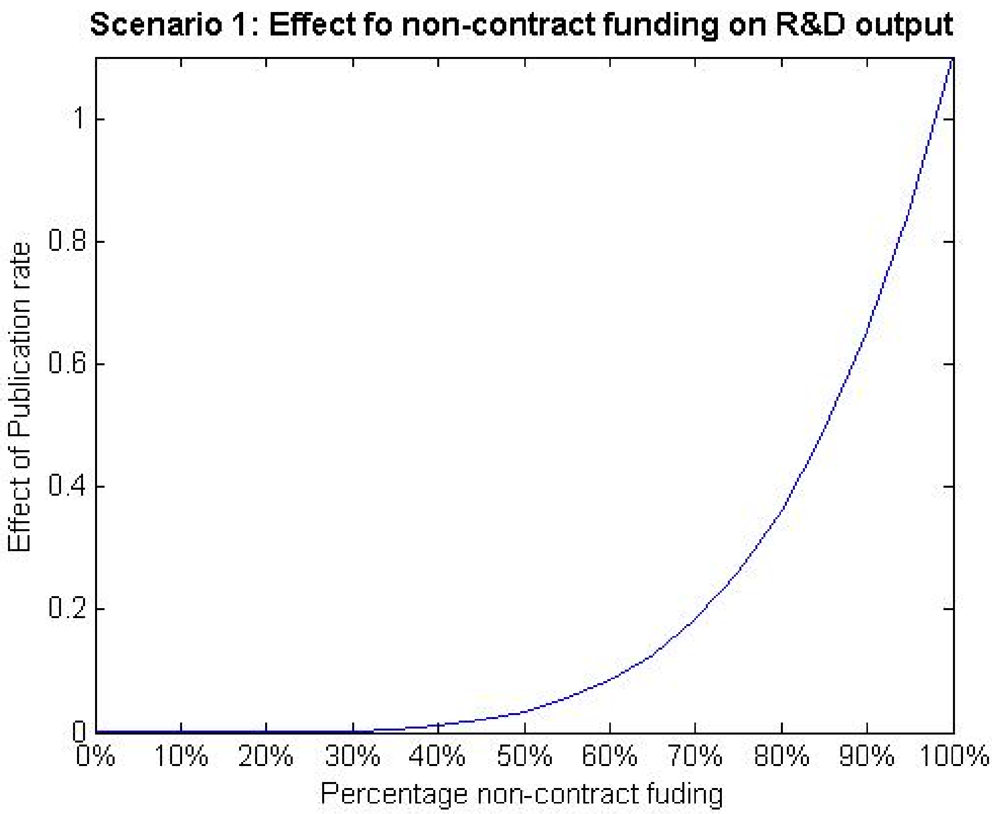



**Figure 8-13: Effect of Non-contract funding on R&D Output**

The following output is obtained from the model. The accuracy with which the trend is recreated is considered to be sufficient for the purpose of this study.

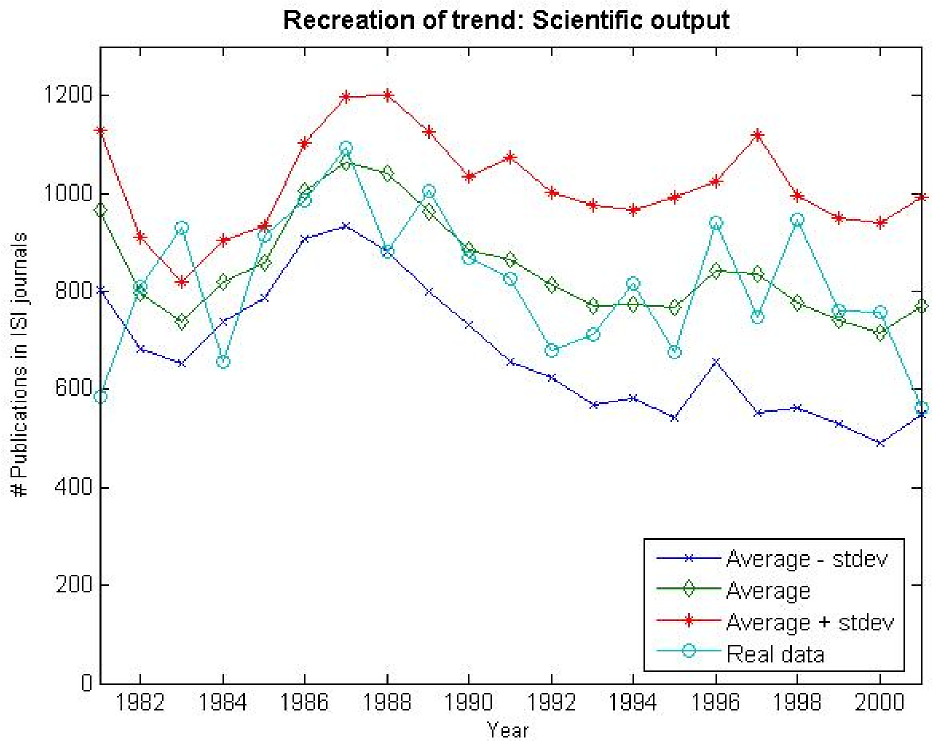



**Figure 8-14: Model Recreation of the Creation of Knowledge Trend Data**

A visual inspection indicates that the general trend is recreated quite well. The actual data gathered is however subject to an amount of fluctuation.

The coefficient of determination ($R^2$), the fraction of the variance in the data explained by the model, is computed at 0.46, which indicates that the average of the model runs equals contains roughly 46% of the variation in the actual data.

### 8.4.3.2 Development rate of knowledge (experimental development)

The production function for the creation of patents in the public sector differs from production functions estimated in the HES and private sectors. This can be ascribed to the lack of a measure for the absorbed knowledge in the public sector due to experimental development. The expression developed does therefore not include the feedback loop from the absorption of knowledge, as developed in the conceptual model. The expression is a simpler one, only taking into consideration the following:

- $R_{Patents}$ : R&D output rate in the system (patents)
- $S_{FTE}$ : FTE researchers in the system
- $A_{ExpDev}$ : fraction of funding directed towards experimental development; and
- $A_{State}$ : the ratio of research expenditure funded by the state, assumed to be directed towards non-contract research.

A multiplicative model is developed for the development rate of papers per fulltime person working in the system:

$$\frac{R_{Patent}}{R^*_{Patent}} = b*(\frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{ExpDev}}{A^*_{ExpDev}} * \frac{A_{Statet}}{A^*_{State}})^a \qquad \textbf{8-7}$$

This expression is linearised by taking the log-linear form:

$$\ln(\frac{R_{Patent}}{R^*_{Patent}}) = \ln(b) + a*\ln(\frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{ExpDev}}{A^*_{ExpDev}} * \frac{A_{Statet}}{A^*_{State}}) \qquad \textbf{8-8}$$

The following expression is thus used to perform the regression for estimating the parameters $a$ and $b$. The regression is executed and the following estimates for the parameters are obtained:

**Table 8-16: Regression Output of the Patent Creation Rate in the Public Sector**

```
                              The REG Procedure
                                Model: MODEL1
                          Dependent Variable: Rdout

                   Number of Observations Read          20
                   Number of Observations Used          20

                             Analysis of Variance

                                     Sum of           Mean
 Source                   DF        Squares         Square    F Value    Pr > F

 Model                     1        1.05369        1.05369      27.02    <.0001
 Error                    18        0.70194        0.03900
 Corrected Total          19        1.75563

             Root MSE              0.19748    R-Square     0.6002
             Dependent Mean        0.12720    Adj R-Sq     0.5780
             Coeff Var           155.24845

                             Parameter Estimates

                                Parameter       Standard
  Variable           DF        Estimate          Error    t Value    Pr > |t|

  Intercept           1         0.02274        0.04852       0.47      0.6450
  ftepattypestate     1         1.02316        0.19683       5.20      <.0001


                              The REG Procedure
                                Model: MODEL1
                          Dependent Variable: Rdout

                            Test of First and Second
                              Moment Specification

                          DF     Chi-Square    Pr > ChiSq

                           2           2.11        0.3488

                            The AUTOREG Procedure

                          Dependent Variable    Rdout

                        Ordinary Least Squares Estimates

         SSE                    0.70194207    DFE                       18
         MSE                       0.03900    Root MSE             0.19748
         SBC                    -4.2437275    AIC               -6.2351921
         Regress R-Square           0.6002    Total R-Square        0.6002
         Durbin-Watson              1.5178    Pr < DW               0.0875
         Pr > DW                    0.9125
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                      Q and LM Tests for ARCH Disturbances
```

```
                 Order            Q    Pr > Q           LM    Pr > LM

                     1       0.0215    0.8834       0.0320     0.8580
                     2       0.1960    0.9067       0.0802     0.9607
                     3       0.9652    0.8097       0.5220     0.9140
                     4       2.5316    0.6390       2.3069     0.6795
                     5       2.5335    0.7714       2.4582     0.7828
                     6       4.7339    0.5784       5.5867     0.4710
                     7       5.0327    0.6560       5.7859     0.5650
                     8       5.3684    0.7176       7.9828     0.4352
                     9       6.8896    0.6486      10.8254     0.2879
                    10       8.3899    0.5908      11.1950     0.3425
                    11       8.4369    0.6737      12.4735     0.3291
                    12       9.1364    0.6912      12.4735     0.4084

                                                Standard                 Approx
      Variable              DF     Estimate        Error    t Value    Pr > |t|

      Intercept              1       0.0227       0.0485       0.47      0.6450
      ftepattypestate        1       1.0232       0.1968       5.20      <.0001
```

The following section summarises the statistical analysis conducted to estimate model parameters. (See section **Error! Reference source not found.** for a detailed discussion).

The **Total** Regress R-Square 0.6002 statistic indicates that the model accounts for 60% of the variation of the percentage time spent by staff on R&D activities. The variable included in the model (ftepattypestate) is highly significant.

The Durbin Watson test statistic is 1.5178 with (Pr < DW = 0.0875 > 0.05 and (Pr < DW = 0.9125) < 0.95, which indicates that the model does not have autocorrelation.

Colinearity tests conducted on the data revealed that all the condition indexes from the regression model are much smaller than 30. We can therefore conclude that no colinearity is present.

The Phillips-Perron test was used to gauge for stationarity, which indicated that all variables included in the model are non-stationary. After fitting the model, it was tested for stationarity. The test proved that the model residual is stationary and the variables are cointegrated, thus implying that the regression is not spurious. We can therefore conclude that the model is not spurious and that we can use the result to develop the model of R&D in the public sector further.

The parameters have therefore been estimated for the following expression:

$$\ln\left(\frac{R_{Patent}}{R^{*}_{Patent}}\right) = \ln(b) + a * \ln\left(\frac{S_{FTE}}{S^{*}_{FTE}} * \frac{A_{ExpDev}}{A^{*}_{ExpDev}} * \frac{A_{Statet}}{A^{*}_{State}}\right) \quad \textbf{8-9}$$

Table 8-17 summarises the variable values as well as the variance introduced into the parameter in the model. The variance of the parameters is set equal to the standard error as reported in the SAS output.

**Table 8-17: Estimated Parameter Values for Patents Creation trend in Public Sector**

| Parameter | Estimate | Variance (s.e.) |
|---|---|---|
| Intercept (b) | 0.0227 | 0.0485 |

| | | |
|---|---|---|
| ftepattypestate (a) | 1.023 | 0.19 |

These parameters with the variance values were used in the model, which yields the following output for the development of scientific output, measured in terms of patents granted at the SAPTO.

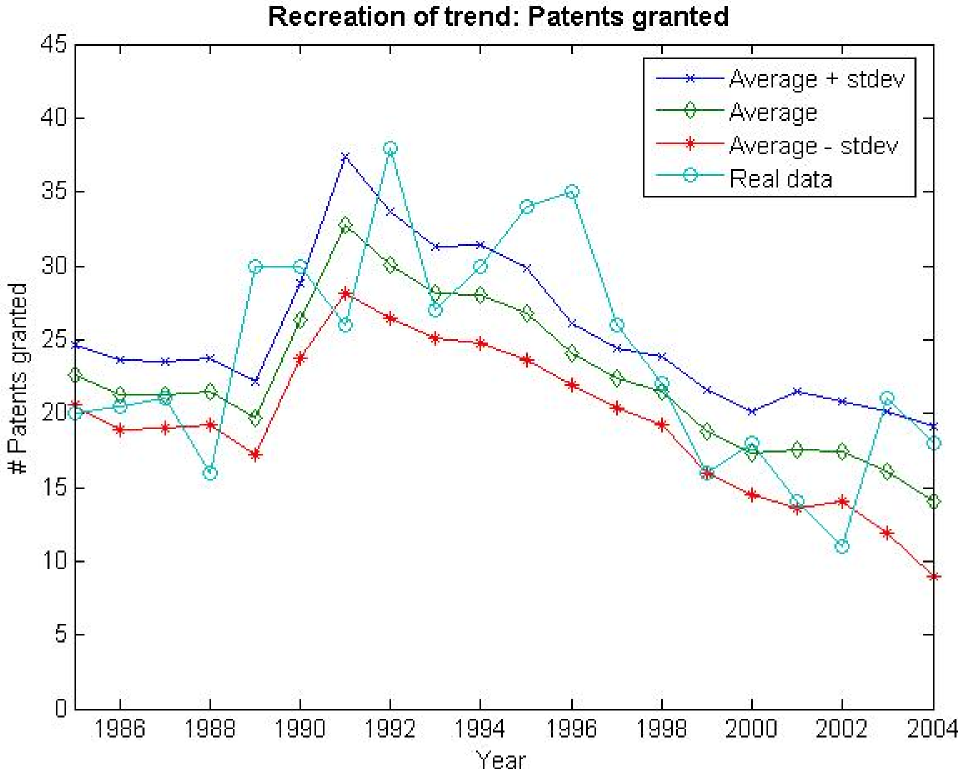



**Figure 8-15: Model Recreation of the Creation of Knowledge Trend Data**

The coefficient of the determination ($R^2$), the fraction of the variance in the data explained by the model, is computed to be 0.60, which indicates that the average of the model runs explains 60% of the variation in the actual data.

## 8.5 Model Simulation

This section documents scenario tests run on the model. These scenario tests were developed from the research questions as well as the Delphi study conducted. The Delphi study was instrumental in finding the foremost issues facing the public sector R&D system in South Africa. Using the Delphi study to develop the scenario tests ensured that the scenario tests developed are relevant in terms of the current concerns of experts working in the system.

The following table relates to the scenarios developed in the Delphi study (see section **Error! Reference source not found.**). The scenario tests run in this section were developed to answer the following questions as described in Table 8-18.

**Table 8-18: The Scenario Tests Runs Executed on the Model**

| |
|---|
| **Base Case:** How would a constant/unchanging investment in the South African public sector R&D system affect its ability to produce R&D output and absorb knowledge? |

**Scenario 1:** How would a decreasing level of government investment in the South African public sector R&D system affect its ability to produce R&D output and absorb knowledge?

**Scenario 2*:*** How would moving away from the Framework autonomy policy influence the system?

**Scenario 3:** How would an increase/decreasing level of investment from government combined with a movement away from framework affect the system's ability to produce R&D output and absorb knowledge?

### 8.5.1 The base case

The base case of the model simulation run is aimed firstly at simulating the model behaviour, should as little as possible change. The following constants are selected for the base case scenario:

- the investment in the hiring of new staff members grow with 0% per year
- the external environment has a 3% increase in knowledge production per year
- the percentage spending from the state and contract funding remains constant; and
- the percentage distribution of funds between basic and applied and experimental R&D remain constant.

To test for the possible outcome in terms of the base case, 100 simulation runs were executed. This section presents output generated by the model of R&D in the public sector. In each figure, the average of the 100 runs as well as the trend lines for the standard deviations are indicated. The variability introduced into the model is a normal distribution for variability on the parameters of 30%.

For a normally distributed variability of 30% in parameter values, the model produces the following output from 100 separate simulation runs executed on the model. The following section describes the model output as well as the conclusions that can be drawn from the sensitivity analysis.

It is imperative that the robustness of conclusions on the uncertainty in the assumptions be tested for the model. The sensitivity analysis tests for changes in conclusions in ways important to the purpose of the model, should variables be varied over plausible ranges of uncertainty.

#### 8.5.1.1 Base case: model output

The following figure represents the model output for patents granted to organisations in the public sector. The simulation is run for the years 1980 to 2030.

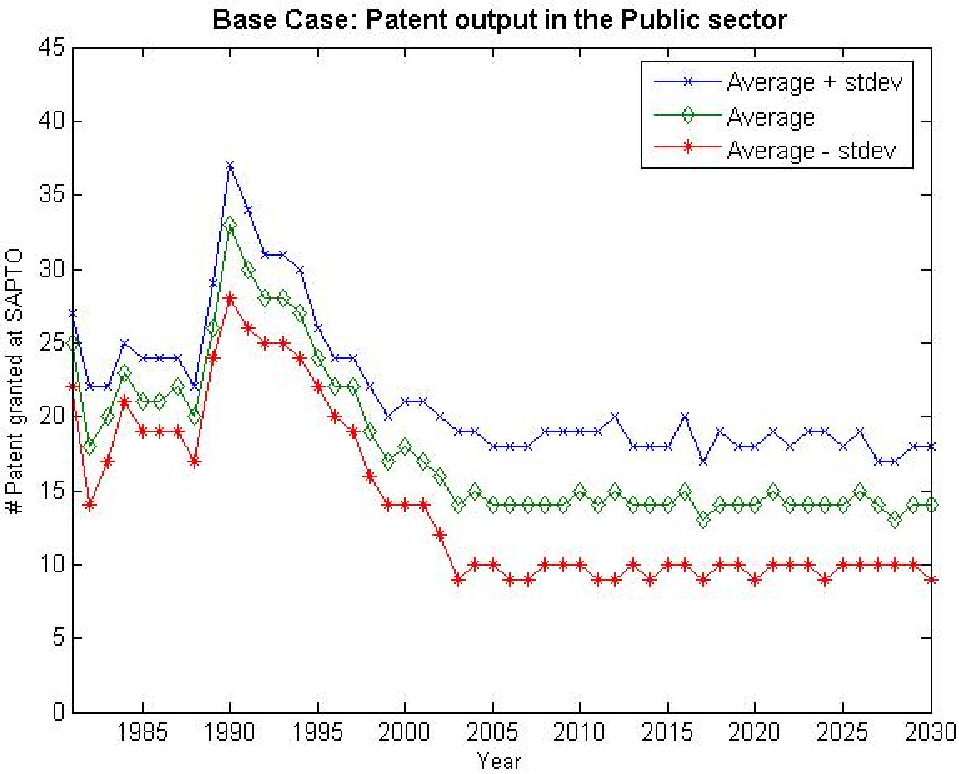



**Figure 8-16: Base Case: Patent Output in the Public Sector**

The Base Case reveals that little or no changes can be expected in the system, should the present situation continue in terms of the amount of FTE R&D staff employed in the system as well as the percentage funding sourced from the private sector, resulting in a constant percentage contract funding.

The model output for the base case scenario reveals the following result for the scientific output created in the system in Figure 8-17.

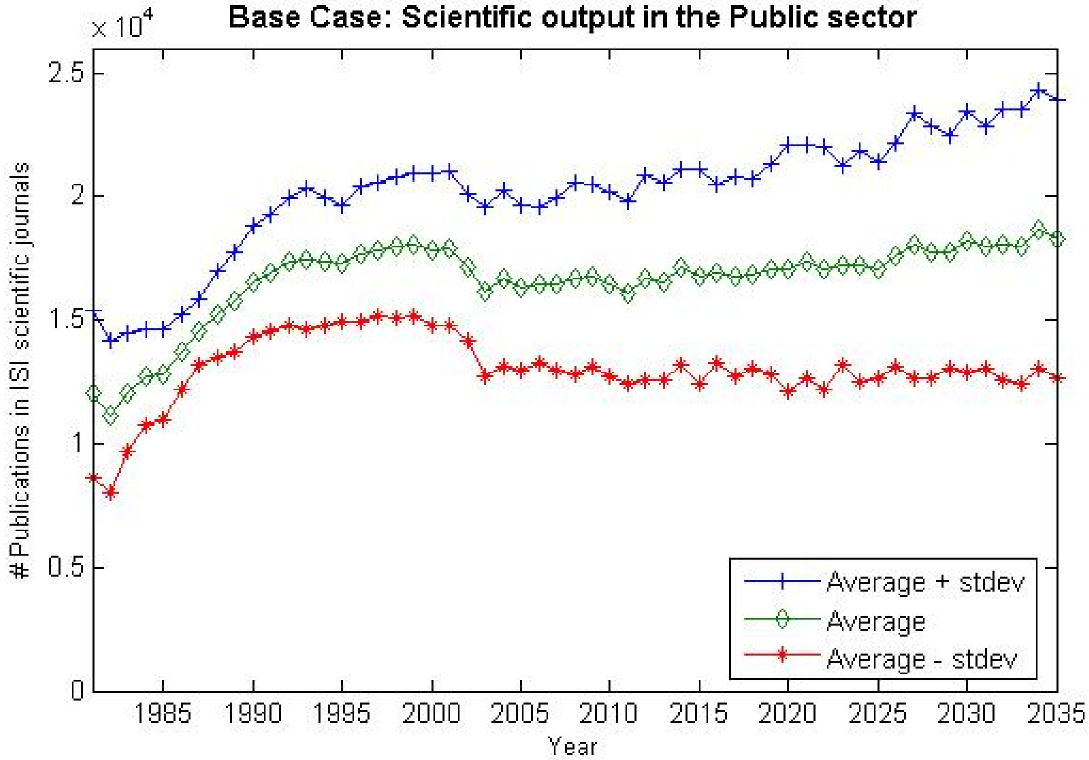



**Figure 8-17:** **Base Case: Scientific Output in the Public Sector**

The following figure represents the predicted rate at which the system will be absorbing knowledge from the external environment.

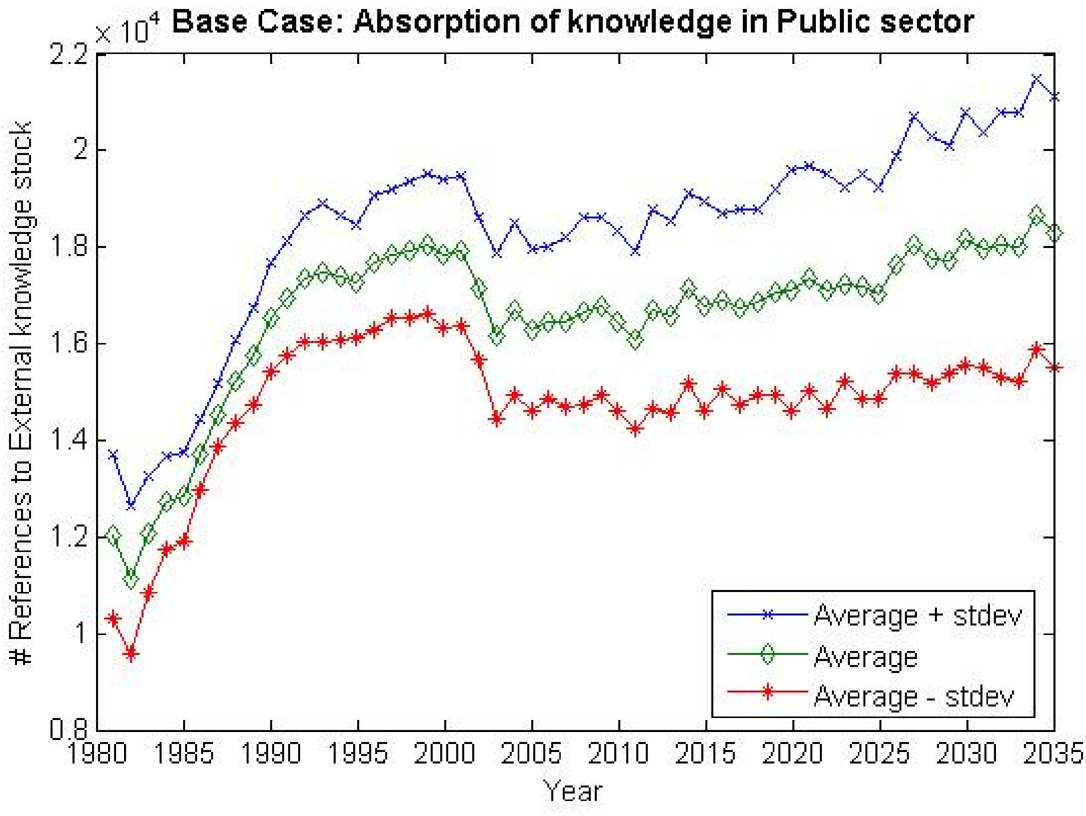



**Figure 8-18:** **Base Case: Absorption of Knowledge in the Public Sector**

The slight increase, which can also be seen in the rate at which the system is absorbing knowledge, can be attributed to knowledge spillovers from an external environment, which continues to produce an increasing amount of scientific output.

In the Delphi study executed in this research project, the experts cited poor prospects for the public sector R&D system to have appropriate funding for R&D in the next 20 years. Questions thus arise around the system's reaction to changing levels of R&D investment (decreasing as well as increasing levels of funding). A scenario is tested on the model to obtain satisfactory answers to these questions.

### 8.5.2 Scenario 1

Scenario 1 aims to run simulations for the predicted outcome, should the R&D expenditure in the system vary:

- the external environment has a 3% increase in knowledge production per year
- the percentage spending from the state and contract funding remains constant, thus 88% state funding and 12% contract funding
- salaries remain constant; and
- the R&D expenditure in the system changes with the following different percentages per year:

**Table 8-19: Test Runs for Scenario 1**

| | Percentage Growth Rate in HES Investment |
|---|---|
| Run 1 | -4 % per year |
| Run 2 | -3 % per year |
| Run 3 | -2 % per year |
| Run 4 | -1 % per year |
| Run 5 | 0 % per year |
| Run 6 | 1 % per year |
| Run 7 | 2 % per year |
| Run 8 | 3 % per year |
| Run 9 | 4 % per year |

The R&D survey for 2003 reported R&D expenditure in the public sector, i.e. science councils and government departments, of approximately R2 210 million. The following investment is the effective increase investment analysed in constant 2003 Rand[3].

[3] The effect of changes in the value of the Rand is ignored and the assumption is made that the ?????

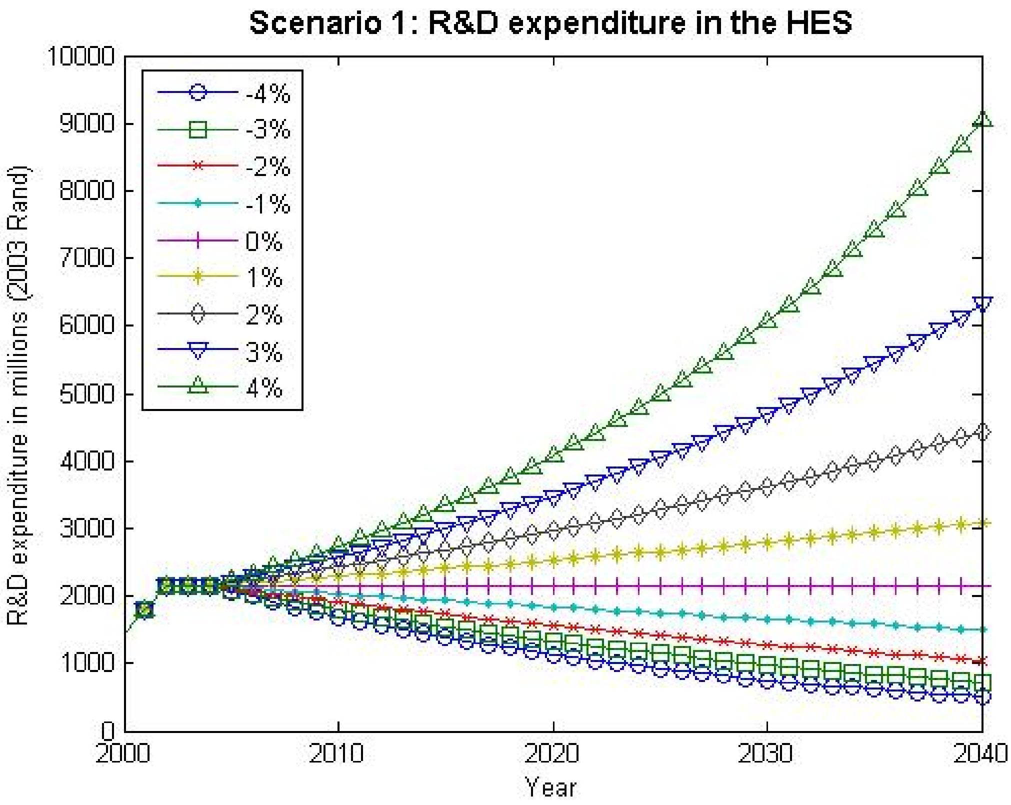



**Figure 8-19: Scenario 1: R&D Expenditure**

Figure 8-19 is a graphical representation of the effect of the percentage increase in terms of R&D expenditure in the public sector. The following figure is a graphical representation of the corresponding changes in terms of headcount of R&D staff in the public sector.

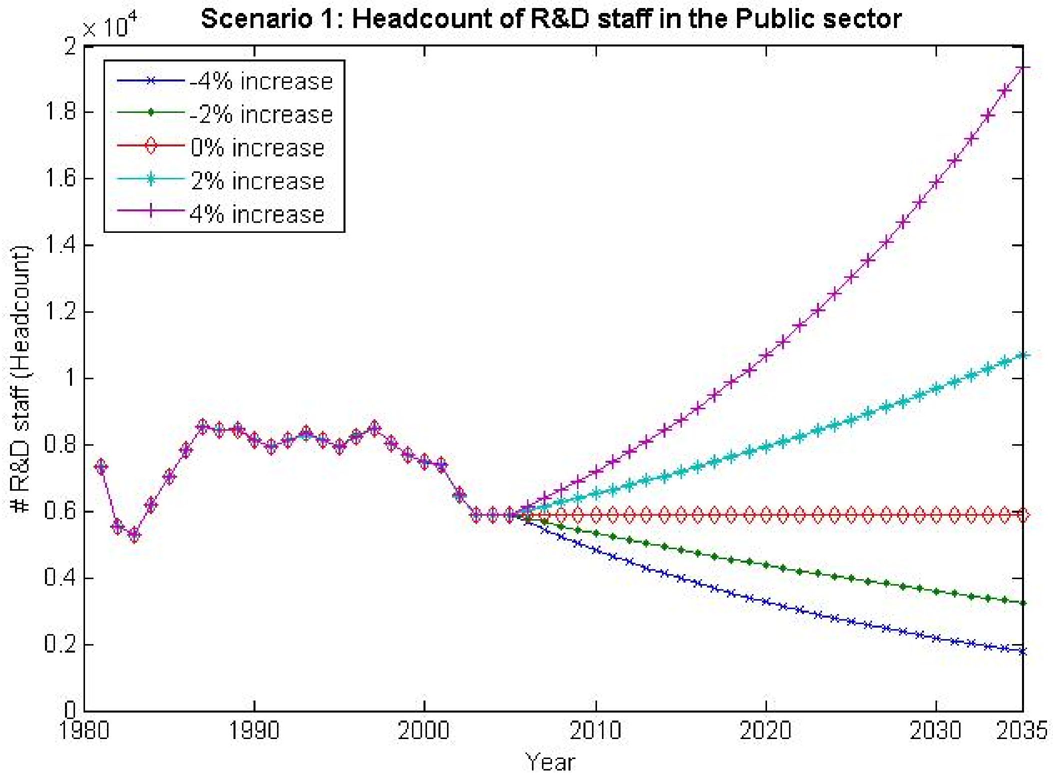



**Figure 8-20** **Headcount R&D Staff Employed in the Public Sector**

As expected, an increase in the funding will result in a higher number of human resources employed in the system (Figure 8-20), resulting in a higher level of patents to be granted to organisations in the public sector (Figure 8-21).

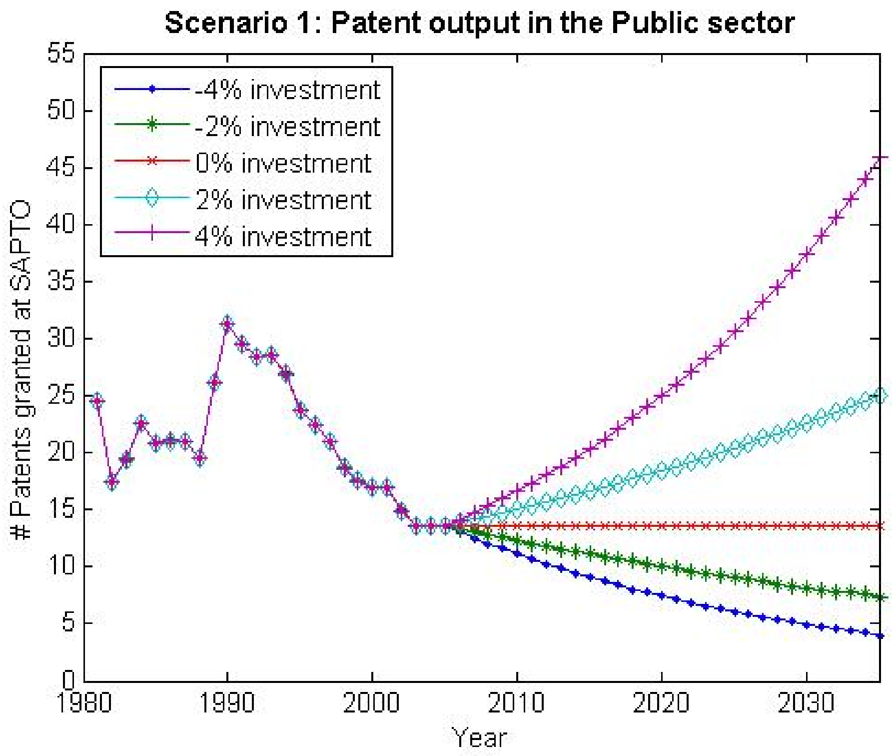



**Figure 8-21** **Patents Granted at the SAPTO to Organisations in the Public Sector**

The following figures present the predicted effect that the different scenarios of change in R&D expenditure might have on the system's ability to produce scientific output in terms of ISI publications.

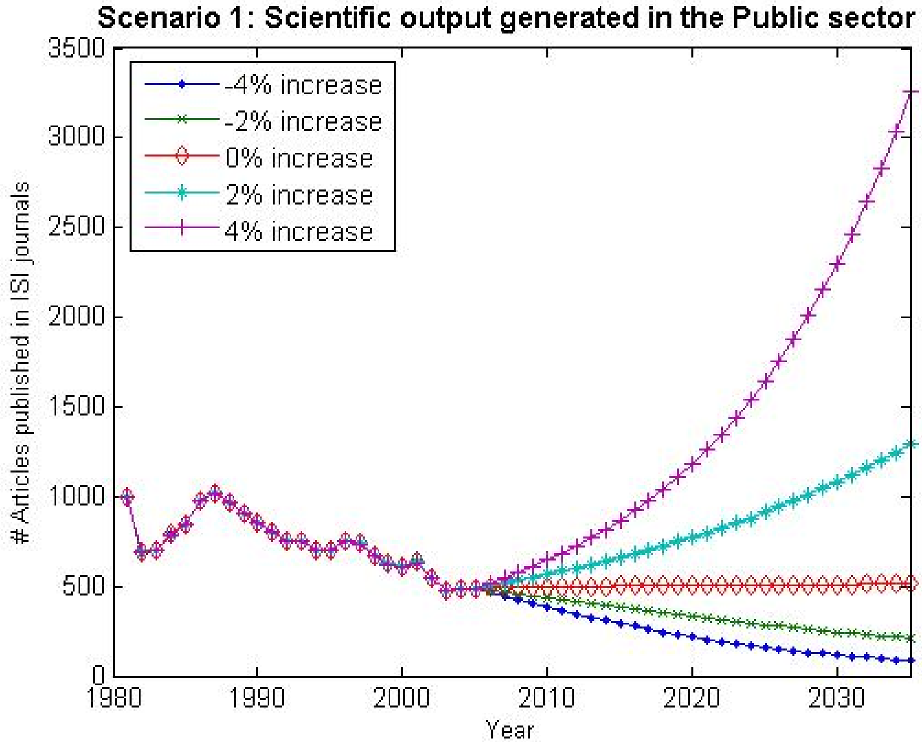



**Figure 8-22:** **Scientific Output Generated in the Public Sector**

Figure 8-22 presents the model output for the development of scientific knowledge in the system. The following figure presents the system's absorptive capacity due to the implementation of the different scenarios.

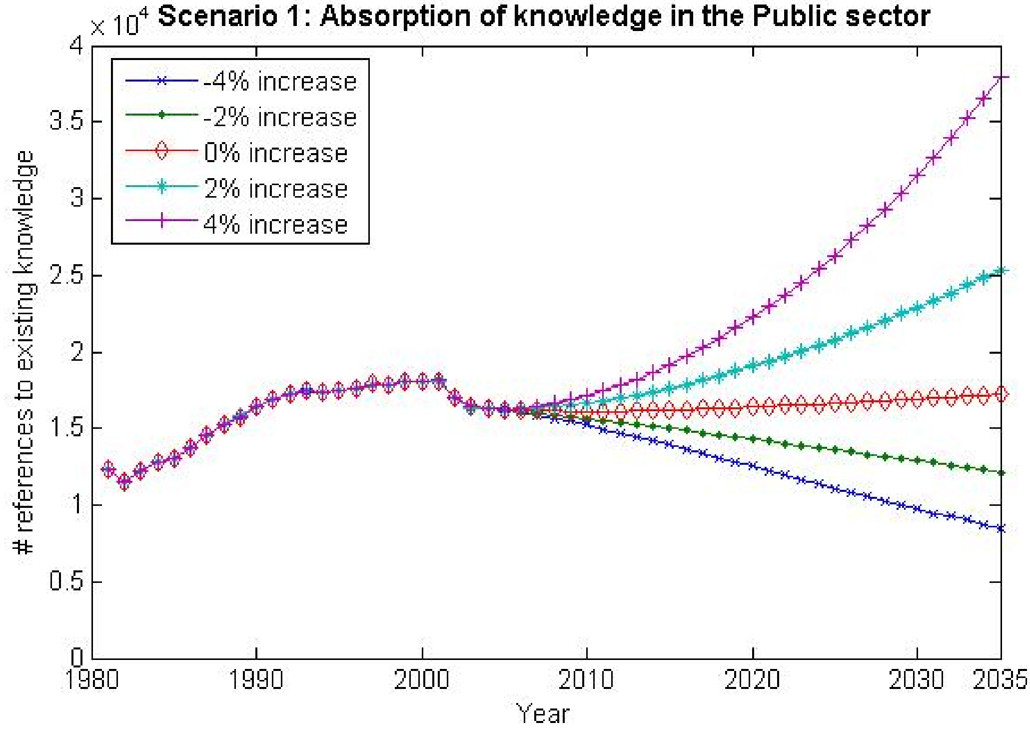



**Figure 8-23** **Rate of Knowledge Absorption in the Public Sector**

As expected, higher levels of R&D expenditure should result in more people employed in the system, which would ultimately lead to higher levels of output.

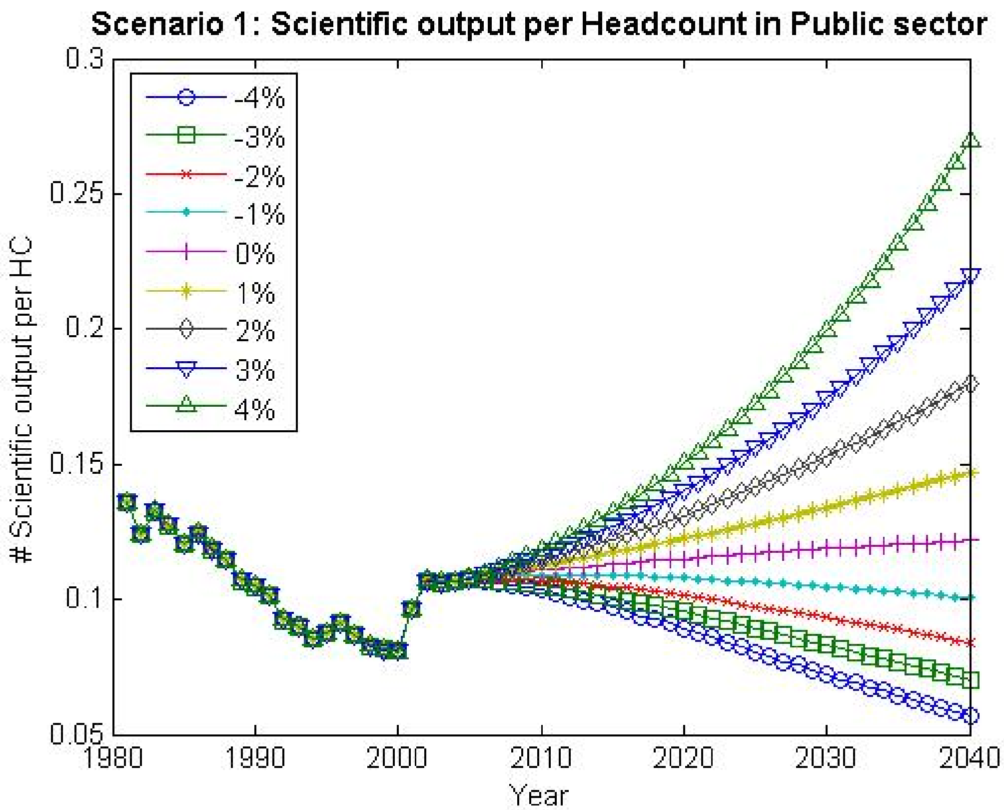



**Figure 8-24: Scenario 1: Papers Produced per Headcount in the System**

It can thus be concluded that through a larger investment, R&D capacity will be developed. It is also evident that an increase in investment will result in an increase in the R&D output generated per worker in the system.

### 8.5.3 Scenario 2

Scenario 2 aims to simulate model behaviour for changes in the total percentage of contract and state funding in the system:

- the R&D expenditure in the sector grows with 0% per year
- the external environment has a 3% increase in knowledge production per year
- salaries remain constant; and
- the distribution of the R&D expenditure sourced from players in the private sector is varied as follows:

**Table 8-20: Test runs for Scenario 2**

| | Percentage Change in R&D Expenditure Sourced for Non-contract Funding |
|---|---|
| Run 1 | -2 % per year |
| Run 2 | -1.5 % per year |
| Run 3 | -1% per year |
| Run 4 | -0.5% % per year |
| Run 5 | 0 % per year |
| Run 6 | 0.5 % per year |
| Run 7 | 1 % per year |
| Run 8 | 1.5 % per year |
| Run 6 | 2 % per year |

Different scenarios were run for the distribution of the percentage of funding sourced for non-contract research. The model produced the following output.

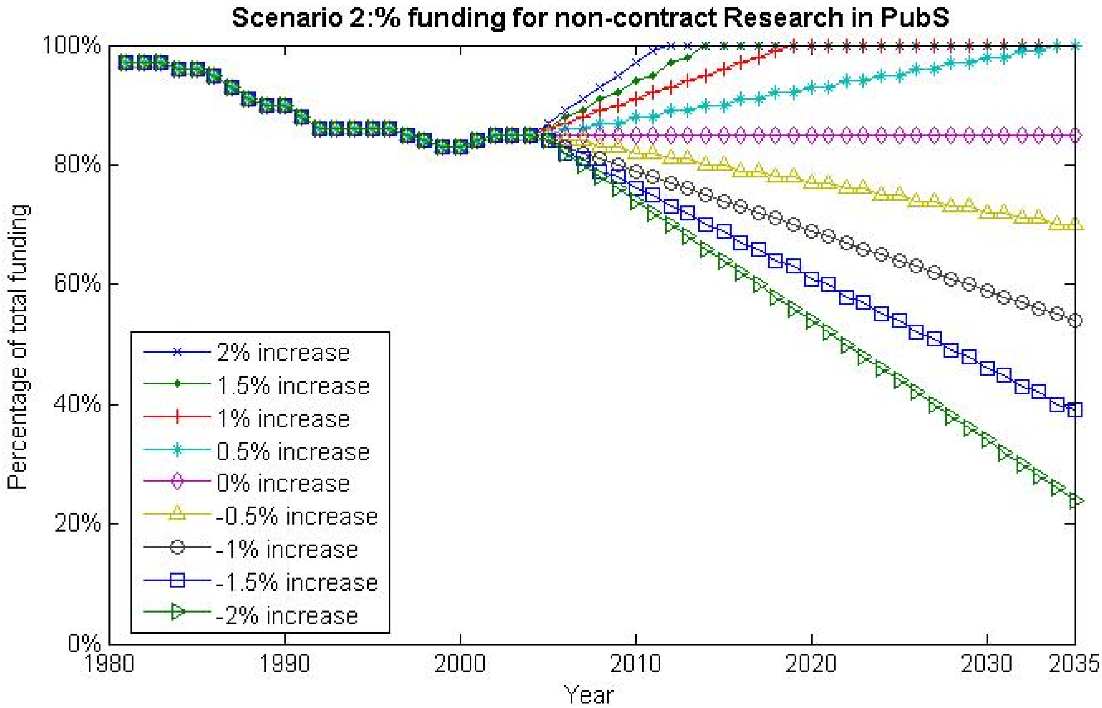



**Figure 8-25: R&D Expenditure from Contact Funding**

The model's reaction on changes of the type of research being conducted is observed. The following graphs represent model output for the different scenarios tested in Scenario 2.

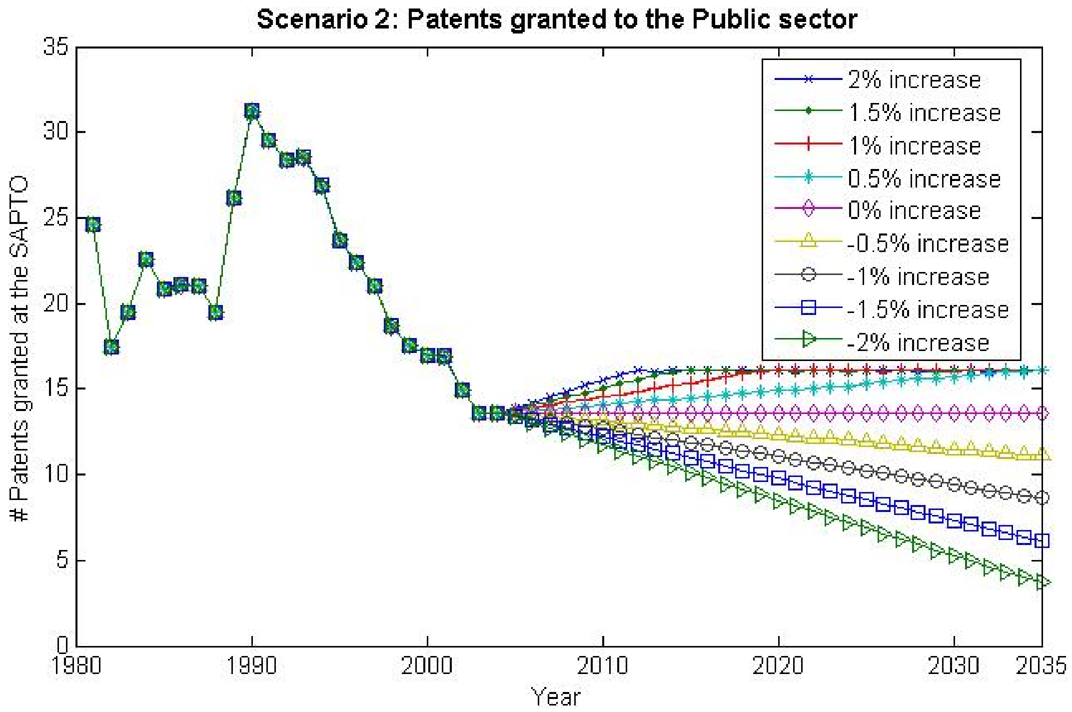



**Figure 8-26: Scenario 2 Model Output for the Patents Generated in the Public Sector**

Figure 8-26 presents the predicted model output for Scenario 2. As expected, a shift in research funding towards more contract research will result in a shift away from the development of patents and scientific output. For the scenario where 100% of all funding is directed toward non-contract research, the system reaches a maximum level for the production of knowledge in its predicted value for the production of new patents. This, in fact, can be contributed to modelled production function that fails to take the absorption of knowledge from the external environment into account, since references to prior knowledge are not included in filed South African patents.

This however is not the case for the production of scientific output in the public sector. Figure 8-27 presents the modelled rate of the absorption of scientific publication knowledge in the public sector.

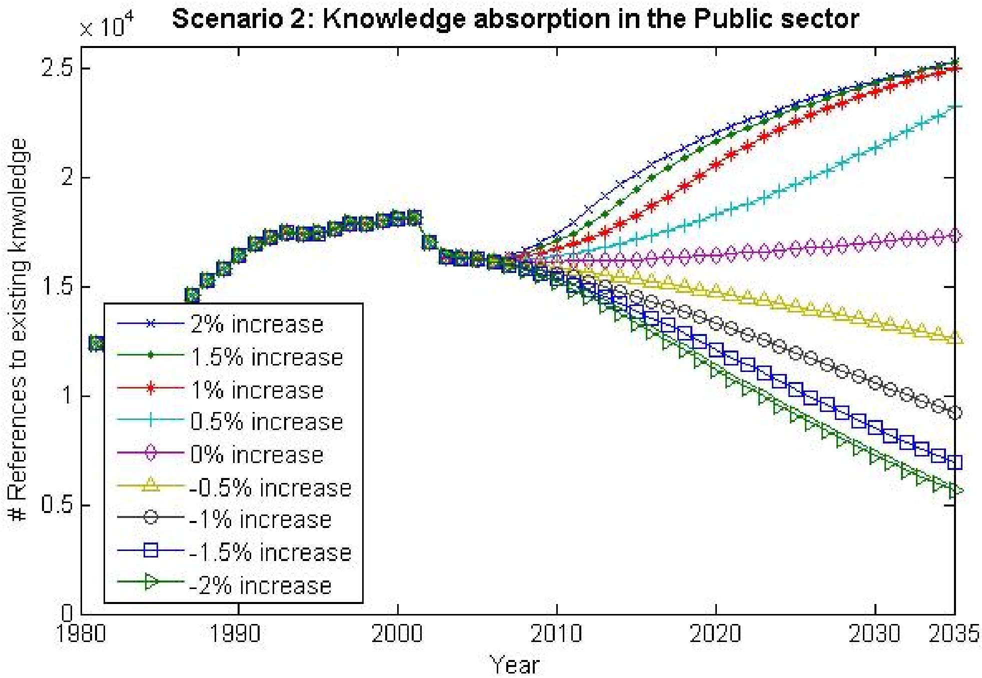



**Figure 8-27: Scenario 2: Absorption of Knowledge in the Public Sector**

Figure 8-27 is a graphic representation of absorptive capacity of the system due to the implementation of the different scenarios. The system's behaviour towards an increased level of contract funding is once again that of a decreasing trend of scientific knowledge absorption. This trend in conjunction with human resources spending a smaller portion of their time on non-contract research also contributes to the resulting decreasing trend in terms of the generation of scientific output from the public sector in Figure 8-28.

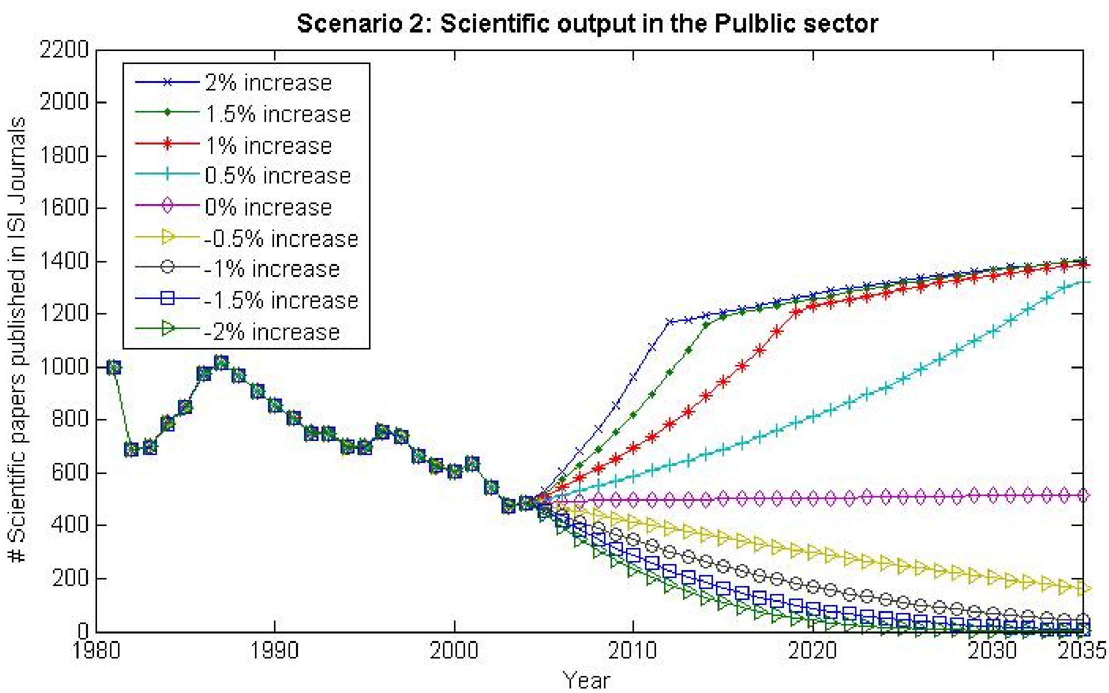


**Figure 8-28: Scenario 2: Scientific Output in the Public Sector**

### 8.5.4 Scenario 3

The analysis executed on the public sector is based on the assumption that R&D expenditure in this sector sourced from the private sector funding is approximated to be an indication of the amount of contract research being done in the public sector.

Scenario 3 aims to examine the model's predicted output for conditions in the system arising from the combination of Scenarios 1 and 2. The effect of changes in the system is tested along two axes:

- Axis 1: change in the R&D expenditure in the system, i.e. change ranges with an increase ranging from -4% to 4% of current expenditure; and
- Axis 2: change in the percentage funding directed towards non-contract funding. (Change in the investment sources ranges from -2% to 2% per annum). The system's reaction to change in the shift of funding towards and away from contract funding is tested.

**Table 8-21: Scenario 3: Changes in System Constants Along Two Axes**

| | -2% | -1.5% | -1% | 0.5% | 0% | 0.5% | 1% | 1.5% | 2% |
|---|---|---|---|---|---|---|---|---|---|
| -4% | | | | | | | | | |
| -3% | | | | | | | | | |
| -2% | | | | | | | | | |
| -1% | | | | | | | | | |
| 0% | | | | | | | | | |
| 1% | | | | | | | | | |
| 2% | | | | | | | | | |
| 3% | | | | | | | | | |
| 4% | | | | | | | | | |

Each cell in Table 8-21 represents a specific scenario tested for. A total of 100 simulation runs were executed for each of these scenarios (cells) in Table 8-21. This means that for each of the cells in the grid, 100 simulation outputs were created for the period 1980 to 2030. To obtain a convenient measure of comparing the different scenarios, the average of these 100 runs is calculated for each cell by computing the average value of the trend from the years 2010 to 2030. This calculation results in a single value that can be represented in the matrix.

The following is a graphical representation of the model output for scenarios run on the grid, where the z-axis represents the human resources in the system working on non-contract R&D in the public sector.

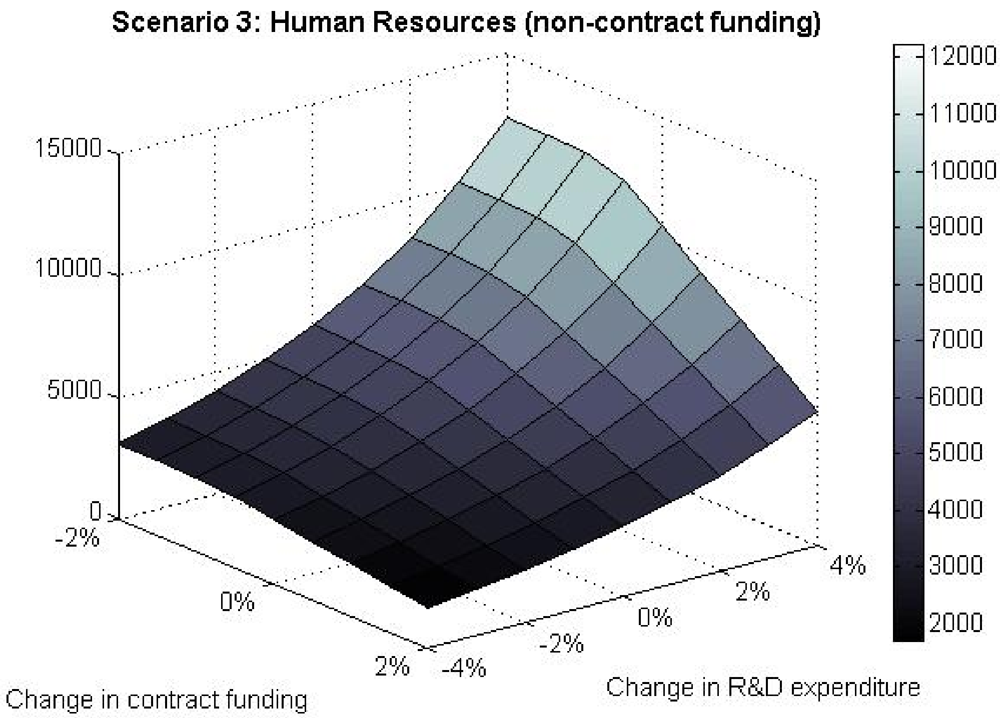



**Figure 8-29: Scenario 3: HR Focusing on Non-contract Funding - Public Sector**

To obtain an expression of the amount of human resources focussing on non-contract funding, the human resources stock in the system is multiplied with the percentage of R&D expenditure sourced for non-contract funding.

This can also be interpreted as the average amount of human resources from 2010 to 2030 which will have to be funded from funds made available to the public sector by the state. The trend in Figure 8-29 therefore indicates that where the sector should move towards a policy of decreasing funding from contract income, it will have to obtain increased government backing to allow the system to continue employing the current levels of human resources in the system.

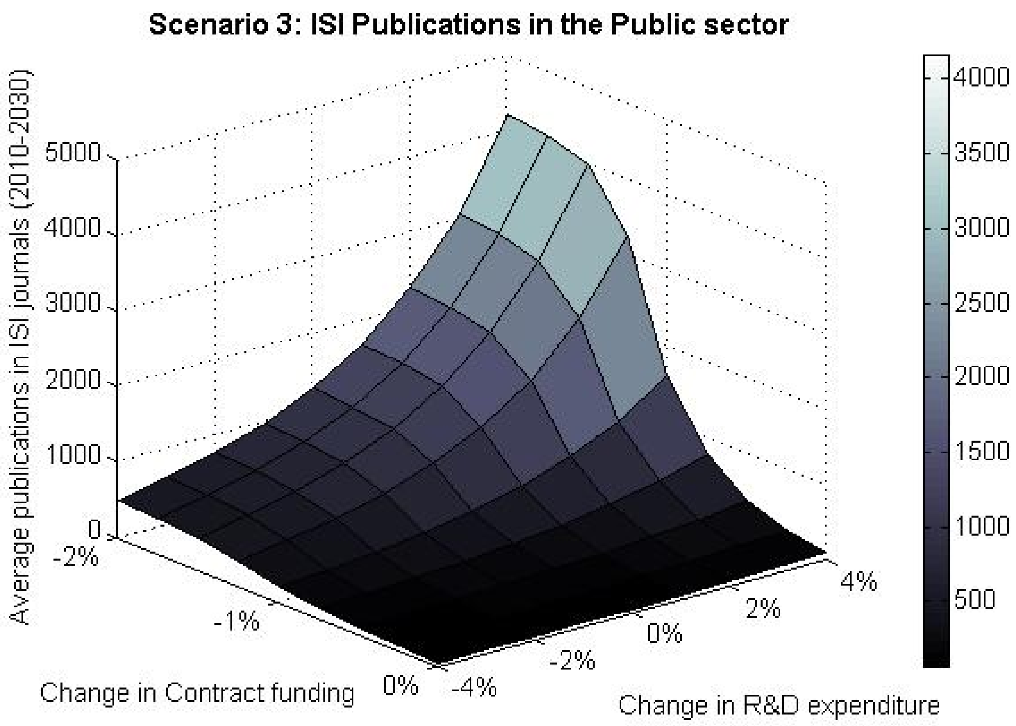



**Figure 8-30:** **Scenario 3: Avg. Publications in the Public Sector (2010 to 2030)**

Figure 8-30 is the graphic representation of the output from simulation runs from different constant values for Scenario 3. As expected, the highest level of ISI publications generated in the public sector could be achieved by increasing the R&D expenditure and by shifting the focus from contract research towards a system where all research is focussed on developing R&D output.

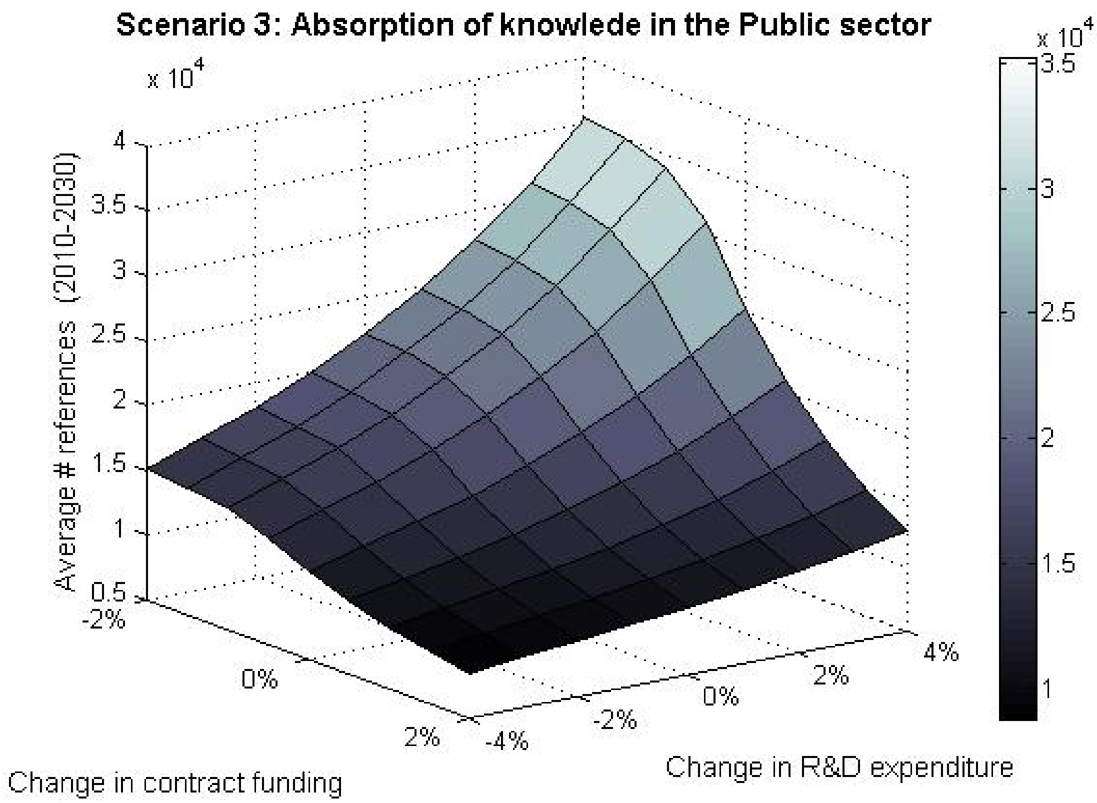



**Figure 8-31:** **Scenario 3: Absorption of Knowledge in the Public Sector (2010 to 2030)**

A similar trend can be observed for the output from the absorption rate of knowledge in the system.

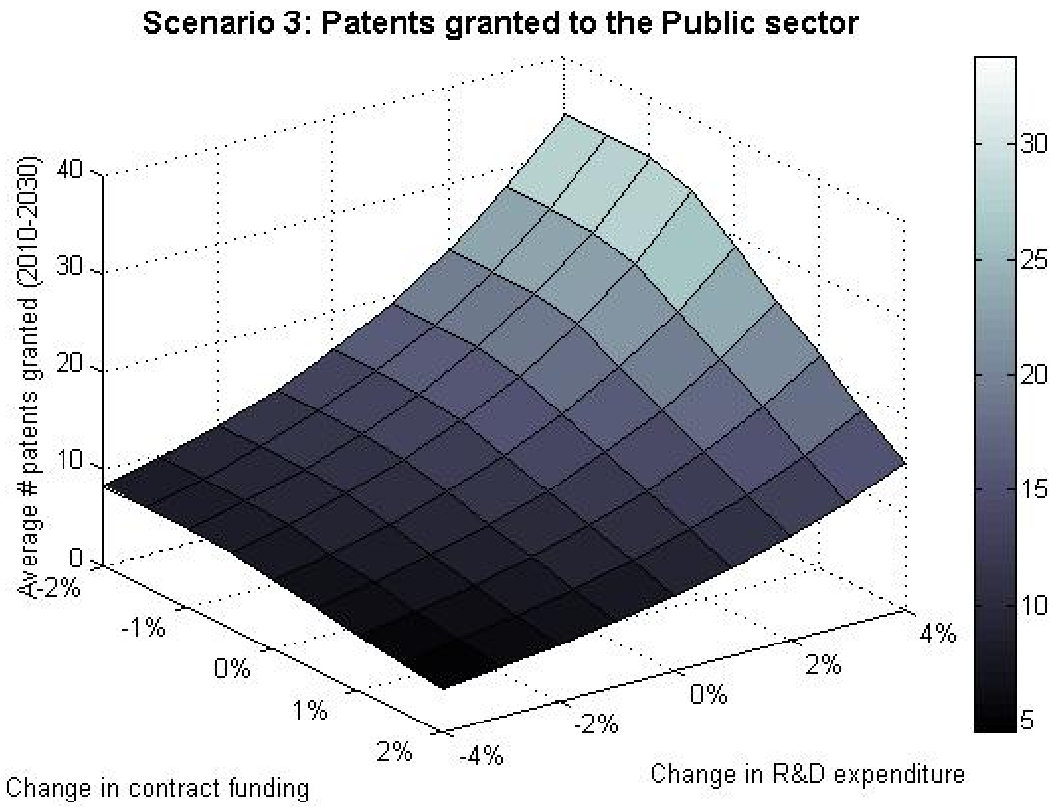



**Figure 8-32:** **Scenario 3: Patents Granted in the Public Sector for (2010 to 2030)**

The model's predicted levels of patent output generated in the public sector reveals that the highest output in the system will be gained through an increase in expenditure and by decreasing the outsourcing of R&D capabilities. It must however be noted that the model's predicted output of the patents granted to the public sector remains low.

The model simulates the dynamic that where government funding increases, the need for contract income will also decrease, resulting in higher tangible R&D outputs. The following figure is a graphic representation of the average funding that will have to be sourced from government for non-contract funding.

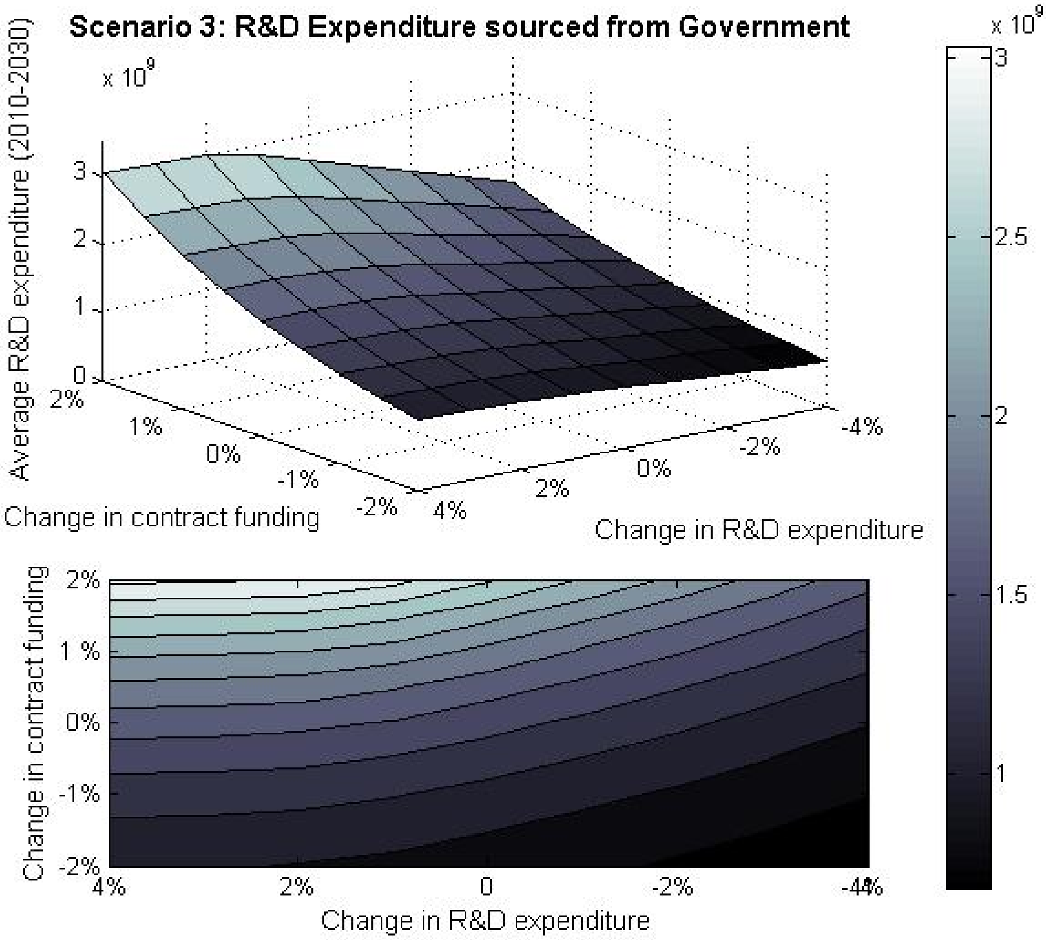



**Figure 8-33:** **Scenario 3: R&D Expenditure Sourced from Government**

Figure 8-33 thus indicates that as the system R&D expenditure is increased and as the percentage of the funding sourced from contract income is decreased, the funding will have to be sourced from government.

## 8.6 Chapter Summary

This chapter documents the data gathering and application of a conceptual model of an R&D performing sector to the South African public sector R&D system.

A regression analysis was performed to estimation parameters and to produce functions of the absorption and creation of knowledge. The explanatory variables included in the model were confirmed to be statistically significant to the explanation of the dependent variables. The following table summarises the coefficients of determination ($R^2$) of the various regressions in the dynamic model:

| Dependent Variables | Regression R-square |
|---|---|
| Patent creation rate | 59.0% |
| Paper creation rate | 47.9% |
| Knowledge absorption rate | 54.0% |

It can thus be concluded that although the coefficients of determination do not have high values, the predictive ability of the model seems to follow the most important trends of the actual data.

Another factor playing a role in the low coefficient of determination achieved for the paper creation rate in the public sector model is the indicator used to measure the applied and basic research output in the public sector. As revealed in the Delphi study, experts did not find scientific output to be a suitable measure of R&D output in the public sector. Given the lack of any better measure available, the author decided to use this measure.

After establishing the model's ability to recreate the historical trend satisfactorily, the model was used to run scenario tests to investigate possible behaviours of the system under conditions specified in the scenario tests.

The base case scenario reveals that should the system be left unchanged in terms of the distribution of the funding as well as the R&D expenditure (in 2003 Rand), the knowledge creation output will remain relatively constant.

Scenario 1 tested the influence of increasing or decreasing R&D expenditure. It is evident that should an increasing number of research staff be employed in the system and should the knowledge stocks in the system increase, the knowledge creation output rate is also bound to increase. As the distribution of funding remains consistent, an increasing R&D expenditure also implies that the system should receive an increasing amount of funding from the state.

Scenario 2 assumes a constant total R&D expenditure in the system. Different scenarios were run on the system to test for the possible effect that the shift in funding towards or away from contract funding might have on the system.

Scenario 3 is run as a combination of Scenarios 1 and 2. Constants in the model are changed along two axes:

- Axis 1: change in the R&D expenditure in the system, i.e. change from -4% to 4% in current expenditure per annum; and
- Axis 2: change in the percentage funding directed towards non-contract funding (change in the investment sources ranging from -2% to 2% per annum). The system's reaction to change in the shift of funding towards and away from contract funding is tested.

The output gained from the model concluded that as the system moves away from framework autonomy and the outsourcing of R&D, R&D outputs are likely to increase. This must however be seen in the light of the fact that the system will then have to receive increasing support from the state.

The following chapter investigates the application of the model to the South African private sector.

# 9 PRIVATE SECTOR MODEL

In this chapter, the conceptual model developed in Chapter 5 is applied to the South African private sector. A similar model structure, employing the construct derived from the theory, is used. As far as the availability of reliable data permits, the quantification of the stocks and flows is chosen to be descriptive of the sector's specific characteristics.

The actual data and data tables gathered is presented in Appendix B, while the discussion of the data as well as conclusions drawn from data trends are discussed in this chapter.

## 9.1 Definition of the Private sector

The Private sector in this thesis follows the same definition as described in the Frascati survey. The reason for this is that this thesis makes use of the data gathered from the Frascati survey. The broad definition of the Private sector is *(OECD, 2002 a)*[1]:

- *All firms, organisations and institutions whose primary activity is the market production of goods or services (other than higher education) for sale to the general public at an economically significant price.*

- *The private non-profit institutions mainly serving them.*

The following section describes the data gathered and the foremost R&D inputs to the absorption and creation of knowledge in the private sector.

## 9.2 Data Gathering and Analysis

### 9.2.1 R&D expenditure

Financial expenditure data is gathered from the South African R&D surveys. The R&D survey data gathered related to the years 1977 to 2003. (See Appendix B for the data tables and data sources.)

**Table 9-1: Data Gathered for R&D Expenditure in the Private Sector**

| Data Input | Source | Table |
|---|---|---|
| Source funding from private sector to P\private sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Source funding from HES to the private sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Own funds private sector (1980-2003) | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure (capital) in private sector | R&D survey (1977-2003) | **Error! Reference source not** |

[1] See The Frascati Manual (OECD, 2002a) for a more detailed description of the followed in the R&D surveys to categorise organisations into sectors.

| | | |
|---|---|---|
| | | **found.** |
| Percentage R&D expenditure (HR) in private sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| - Expenditure on researchers<br>- Expenditure on technicians<br>- Expenditure on support staff | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on basic R&D in private sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on applied R&D in private sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage R&D expenditure on experimental development in private sector | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Investment in capital stock in private sector | R&D survey (1977-2003) | **Error! Reference source not found.** |

Table 9-1 lists the data gathered of R&D expenditure in the private sector from the R&D surveys from 1977 to 2003.

The data gathered from the R&D surveys concluded that an average of 11% (with a standard deviation of approximately 5%) of the total expenditure was directed towards capital. The available data did not yield much detail in terms of the type of investment to different fields of science or the type of capital resources. Land and buildings are also included in the investment data.

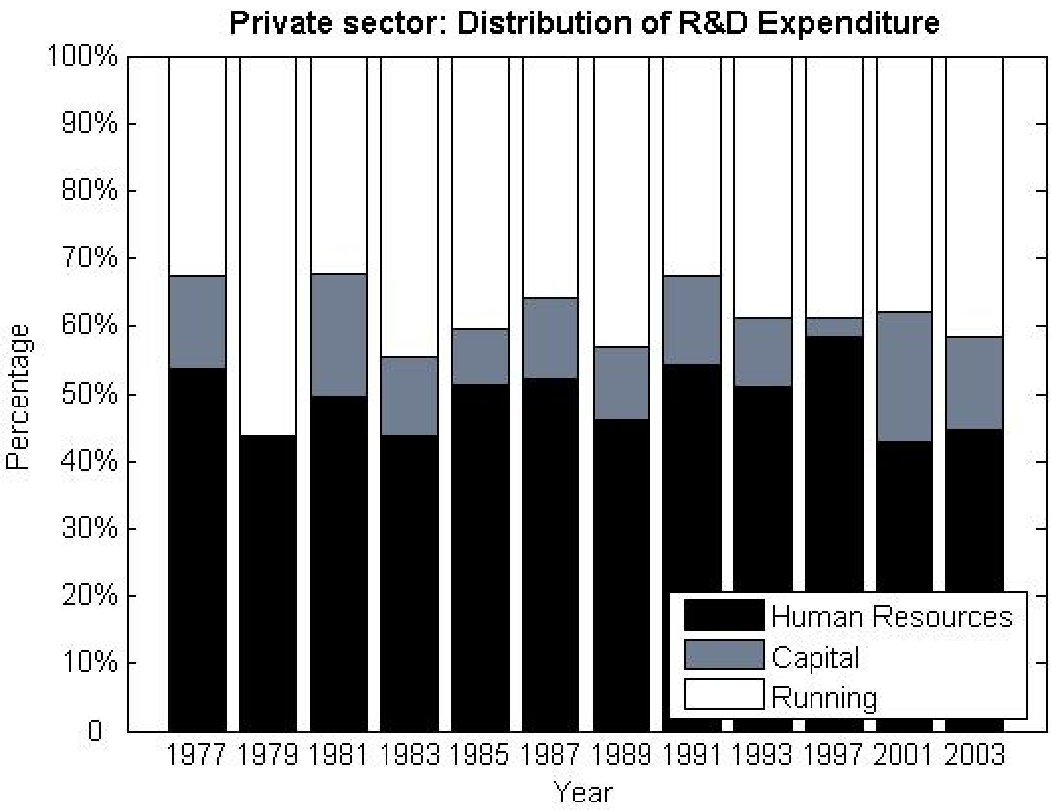



**Figure 9-1: Private Sector: Distribution of R&D Expenditure**

As depicted in Figure 9-1, the calculation of the percentage of R&D expenditure on labour in the private sector seems to be a relatively constant percentage of approximately 49.28% of the total expenditure in the system. The average of the percentage for the years 1977 to 2003 is 49.28%, with a standard deviation of 5.07%.  The above indicates that human resources have been one of the main sources of expenditure on R&D in the private sector.

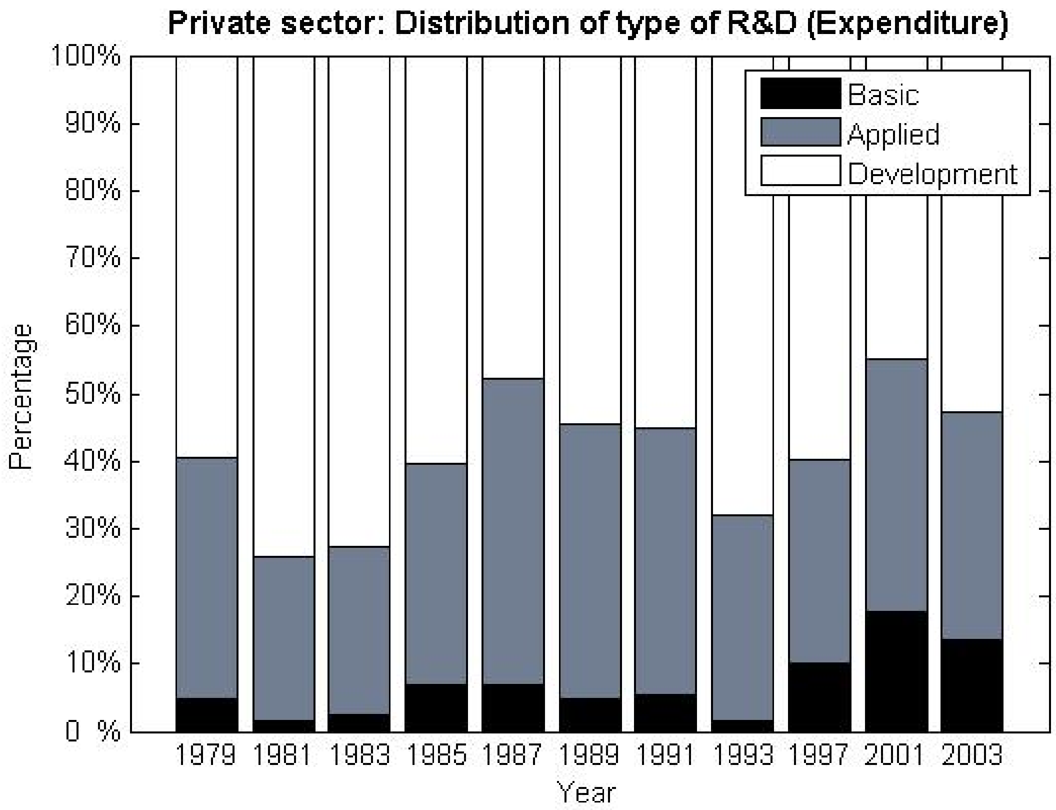



**Figure 9-2: Private Sector: Distribution of Type of Research (Expenditure)**

The private sector focuses mainly on experimental development and applied research. Over the period 1979 to 2003, an average of roughly 34% of R&D expenditure in the sector was directed towards applied research, while an average of approximately 59% was directed towards experimental development over the period 1979 to 2003.

The following table summarises the analysis of R&D expenditure in the South African private sector.

**Table 9-2: Conclusions from Private Sector Expenditure Data Gathered**

| Parameter | Average for 1977 to 2003 | Standard Deviation |
|---|---|---|
| Percentage R&D expenditure (capital) in HES | 11% | 5% |
| Percentage R&D expenditure (human resources) in HES | 49% | 5% |
| Percentage expenditure on basic research<br>Percentage expenditure on applied research<br>Percentage expenditure on experimental development | 6.6%<br>34.4%<br>59% | 5.2%<br>6.7%<br>10% |

### 9.2.2 Human resources in the private sector

**Table 9-3: Data Gathering for Human Resources in the Private Sector**

| Data Input | Source | Table |
|---|---|---|
| Total human resources stock (1980-2003) | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Fulltime equivalent researchers | R&D survey (1977-2003) | **Error! Reference source not found.** |
| Percentage time spent on R&D | To be computed from Survey | **Error! Reference** |

| | | |
|---|---|---|
| | | **source not found.** |

Both the headcount as well as fulltime equivalent human resources data was gathered from the Frascati surveys. (**See Appendix B for more details**). The fulltime equivalent R&D staff is calculated from the surveyed researchers and the percentage time they spent on R&D.

Since the Frascati surveys were conducted biannually, the data points in the time series process is only available for every second year. The data on the R&D output generated in the system is however available yearly. Since the human resources in Figure 9-3 clearly illustrate a definite trend, the data is thus extrapolated to be compatible with the R&D output data available for every year.

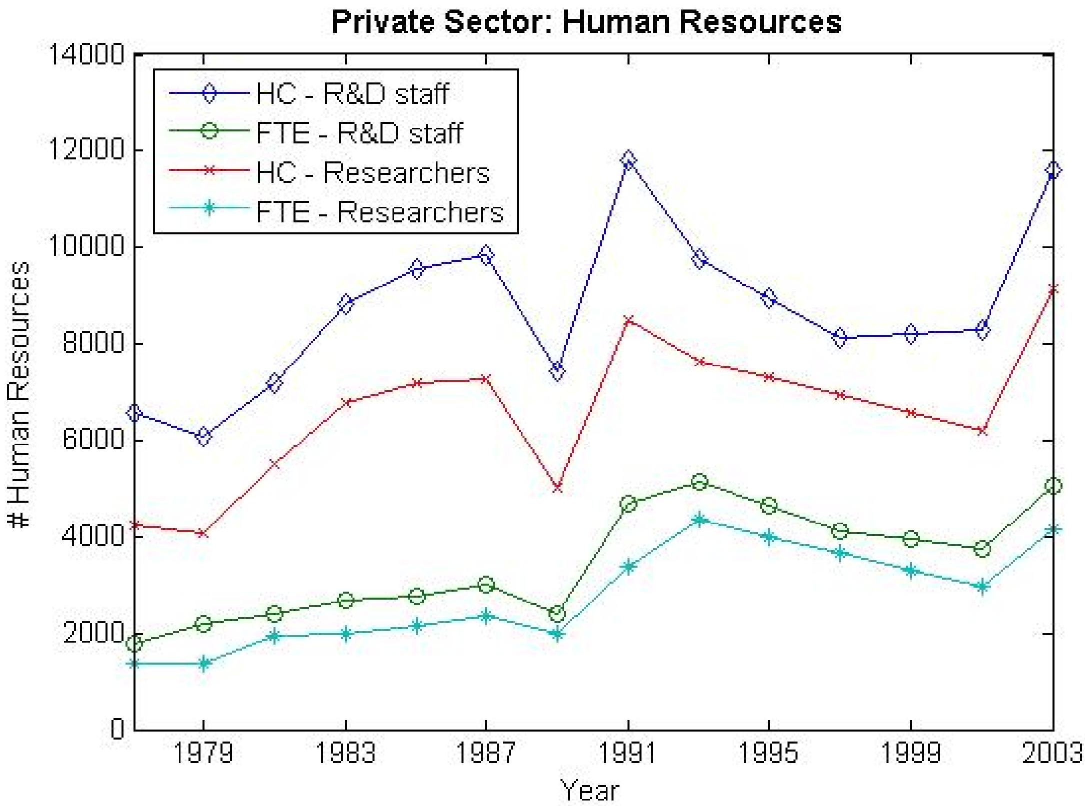



**Figure 9-3 R&D Human Resources in the Private sector**

The 1980 R&D survey reported a total of 6 569 headcount staff working in the private sector. To initialise the three human resources stocks in the private sector, the assumption is made that staff was perfectly mixed across all age groups. We therefore calculate the initial values from the stocks as described in the following table:

**Table 9-4: Initial Values for the Human Resource Cohorts in the Private Sector Model**

| Age | Years | Percentage | Starting Values |
|---|---|---|---|
| 25-40 | 15 | 42.86% | 2815 |
| 41-50 | 10 | 28.57% | 1876 |
| 51-60 | 10 | 28.57% | 1876 |

To calculate the percentage of time personnel spent on R&D, the fulltime equivalent R&D staff is divided with the headcount R&D personnel, which then reflects the percentage time that R&D personnel spent on R&D activities:

- percentage all staff: FTE staff (survey)/HC staff (survey); and
- percentage researchers: FTE researchers (survey data) per HC researchers (survey).

The percentage time spent on R&D activities is calculated at an average of approximately 73% (deviation 4.86%) for the years 1977 to 2003. The average time spent by researchers in the system is fairly similar at 77.52% (deviation 5.94%).

The conclusion can therefore be drawn that R&D staff in the private sector spends roughly 75% of their time on R&D.

**Table 9-5: Conclusions from Private Sector Human Resources Data Gathered**

| Parameter | Average for 1977 to 2003 | Standard Deviation |
|---|---|---|
| Percentage time spent on R&D (all personnel) | 73.14% | 6.59% |
| Percentage time spent on R&D (researchers) | 77.52% | 5.94% |

### 9.2.3 The development of knowledge (private sector)

In the previous sections, we have determined that apart from basic research, the private sector also performs a large amount of applied and developmental research.

From an analysis on the scientific publications generated in South Africa, it can be concluded that a very small percentage of ISI scientific publications is produced in this sector.

The sector's R&D outputs are measured by the amount of patents registered by the South African companies at the USPTO. The following figure is a graphical representation of the respondents' feedback on the applicability of patent counts as a proxy for R&D output in the South African private sector (see section **Error! Reference source not found.**).

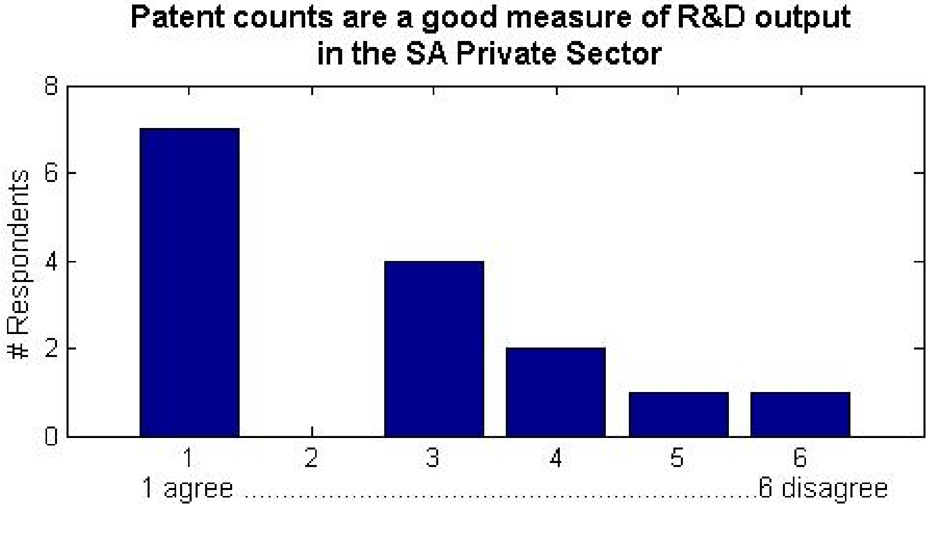



**Figure 9-4: Patents counts as a measure of R&D output created in the Private sector**

The responses illustrates that the mode is 1, seven of the respondents agreed (rank = 1) that the use of patent output is a suitable measure of R&D output in the private sector. We can also conclude that from the 12 respondents, only four ranked above three. The above therefore indicates that patent output is a relatively good measure of experimental development output in the South African private sector.. This approach does naturally have its weaknesses, which is also reflected in the average rating of 2.54 by the expert panel.

| Data Input | Source |
|---|---|
| Sector knowledge creation (USPTO NBER database) (1977-1997) | ISI Web of Science, South African Patent Office |
| Knowledge depreciation rate (citation curve) | USPTO NBER database (1977-1998) |
| Sector knowledge creation (patents) (1980-2003) | SAPTO |
| Knowledge depreciation rate (citation curve) | To be estimated |

Pouris (2005) has used the patents granted to South Africans at the United States Patent Office (USPTO) to analyse the technical performance of South Africa. This approach is also followed in this thesis to measure the performance of the Private sector. The following is a graphical representation of the patents granted to the South African private sector at the United States Patent Office.

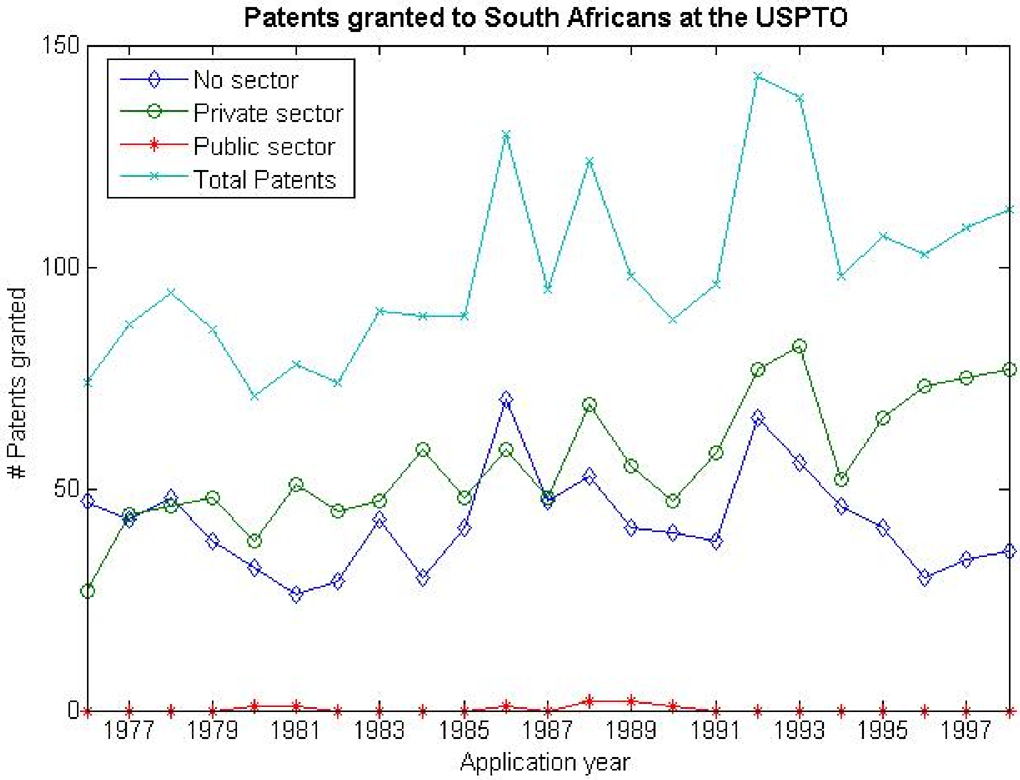



**Figure 9-5 Scientific output generated in the South African Private sector**

Data obtained form the USPTO for the period 1977 to 1998, indicates that the South African private sector revealed a slight increasing trend in patents granted over the past two decades.

### 9.2.4 Absorption of knowledge

| Data Input | Source |
|---|---|
| Rate of knowledge absorption (references) | ISI Web of Science |
| Initialisation of absorbed knowledge stock in 1980 | To be estimated |
| Depreciation of acquired knowledge stock | To be estimated |
| Initial Acquired knowledge stock in 1980 | To be estimated |

Since patents are used to measure the development of new knowledge in the sector, the absorption of knowledge is thus measured by the rate at which scientists are reading, interpreting and using knowledge created in the external environment to produce new knowledge.

The prior art cited in the patents granted to South Africans at the USPTO is used to measure the absorption of knowledge. See Section **Error! Reference source not found.** for a detailed discussion on the use of patents and citations as a measure of knowledge.

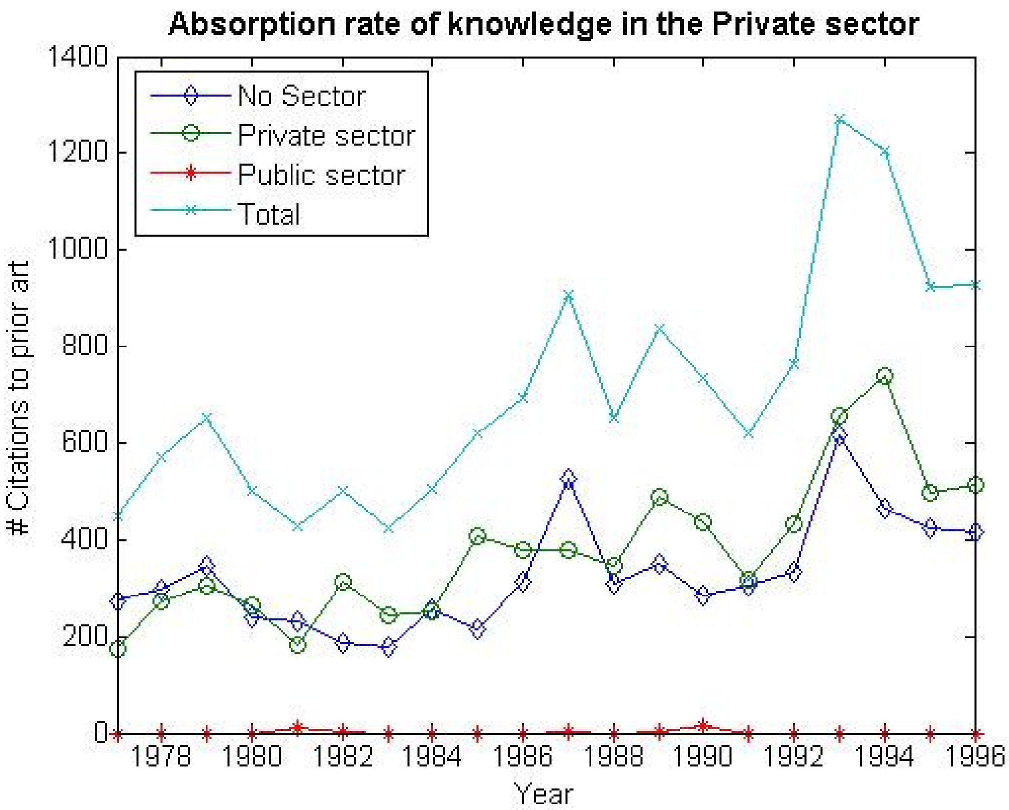
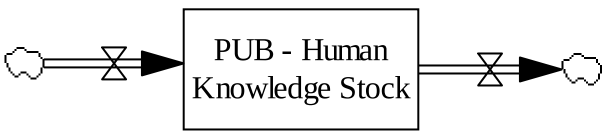


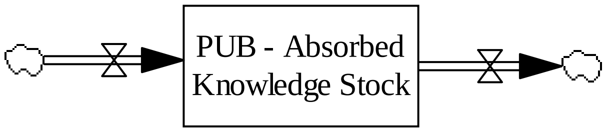
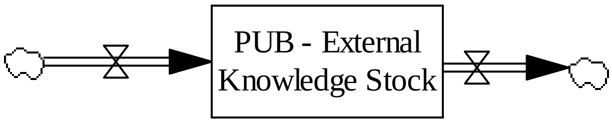

**Figure 9-6.Number of references made to knowledge created in an external environment.**

## 9.3 Quantification of Stocks in the Private Sector

The above discussions result in the following table, which describes the unit of measurement and quantifications of stocks in the private sector model:

**Table 9-6: Stocks in the Private Sector Model**

| Stock | Quantification |
|---|---|
|  PUB - Human Resources Stock | Headcount – research personnel employed in the system<br>Unit: Research personnel |
|  PUB - Human Knowledge Stock | Cumulative years experience of researchers<br>Unit: Year (FTE researchers) |

| | |
|---|---|
|   | R&D output generated in private sector. Unit: Patents |
|   | Stock of absorbed knowledge is measured by counting the amount of foreign papers cited by scientists in the system. Unit: Patent citations |
|   | The stock of external knowledge is measured through the amount patents in the external environment. Units: Patents |

## 9.4 Developing the Model

**See appendix H for the stock and flow diagram of the South African Private Sector R&D system**.

This section describes the actual population of the model with the data gathered. The first subsystem developed concerns human resources. The following parameters are assumed in the model:

**Table 9-7: Parameters for Estimation in the Private Sector Model**

| Parameter | Estimated Value |
|---|---|
| Average retirement age | 65 years |
| Recruitment distribution between cohorts:<br>• young<br>• experienced<br>• mature | <br>77%<br>11%<br>11% |
| Natural attrition percentage of cohorts:<br>• young<br>• experienced<br>• mature | <br>5%<br>5%<br>5% |
| Initial for the human resource stocks (1980):<br>• young<br>• experienced<br>• mature | Total:<br>2815<br>1876<br>1876 |
| Decay rate of knowledge stocks and experience | 10 % per year |
| Average time spent on R&D | 0.75 (5% variation) |

### 9.4.1.1 Experience stock

The experience stock employs the co-flow structure as discussed in the development of the conceptual model diagram in Chapter 5. The experience gained from doing research is measured in terms of the FTE researchers working in the system during a specific timeframe.

An initial experiment was conducted on the model to test its behaviour of the development of experience in R&D. All experience stocks were initialised with zero values. The target academic and research staff in the system was set to be a constant value of 6 500. The percentage time spent by researchers on R&D was set to be 75%.

An examination of the average level of experience possessed by the different age cohorts of academic and research staff as the system reaches equilibrium yielded an interesting observation. Figure 9-7 depicts the output from the model for the simulation run for a constant average of 75% time spent on R&D.

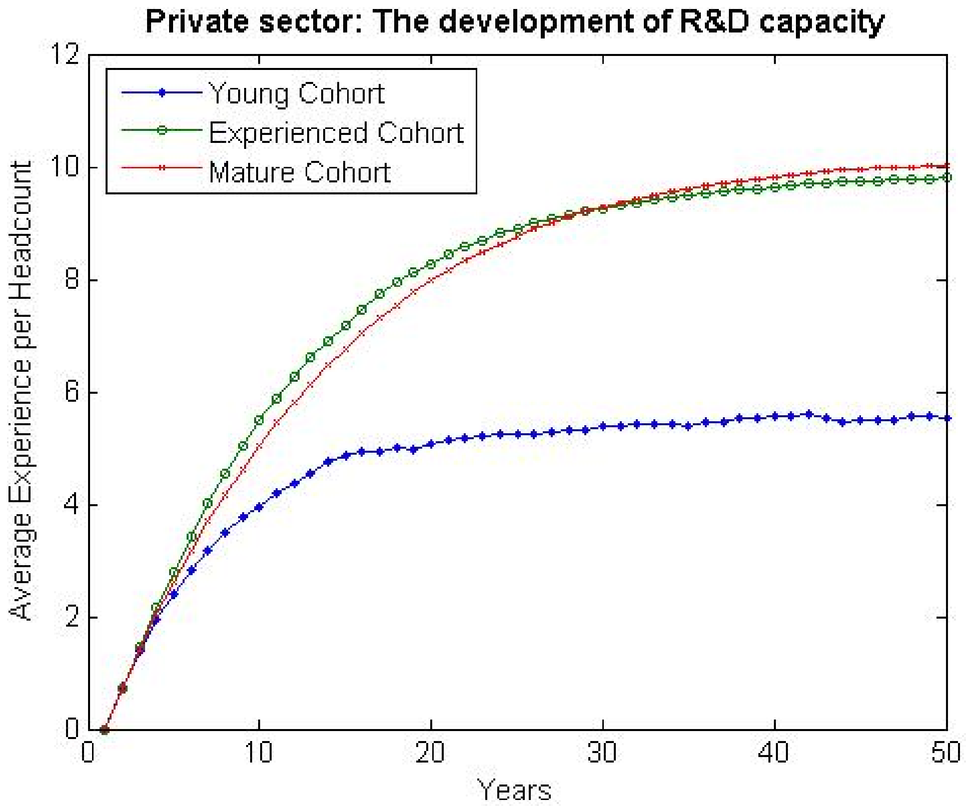



**Figure 9-7 The Development of an R&D capacity (Age Cohorts)**

Figure 9-7 reflects the expected trend that young researchers will not have the same capabilities and tacit knowledge than older, more experienced researchers. The equilibrium levels of experience per person approach the same value for both the experience and mature researchers stocks. This phenomenon can be explained by the dynamic included in the model that knowledge also decays through ‘forgetting’ and that for a fixed R&D intensity, the system approaches an equilibrium level where only knowledge gained within a given amount of years are in the system.

It can therefore be concluded that the system reaches a state of equilibrium after a number of years.

The system has three experience stocks, one for each age cohort. In this section, the initial values for the experience stock are also estimated. **It is assumed that the system is in equilibrium in 1977**. Working from this assumption, the average years experience per research personnel is estimated through the equilibrium levels and the initial level of years experience in the system. This is summarised in the following table:

**Table 9-8: Initial Values for the Experience Stocks**

| Stock Name | Initial Value |
|---|---|

| | |
|---|---|
| Young experience stock (25-39) | 14075 (years) – 2815 personnel with five years experience |
| Experienced experience stock (40-49) | 18760 (years) – 1876 personnel with ten years experience |
| Mature experience stock (50+) | 18760 (years) – 1876 personnel with ten years experience |

### 9.4.2 Parameter assessment test

Parameters are assessed statistically by employing regression analysis. Two rates are modelled by using the stocks built up in the system.

#### 9.4.2.1 Development rate of knowledge

Regression analysis was used to develop the following model for the production of new knowledge output. The rate at which the system is able to produce new knowledge output is calculated by the contribution made from different stocks in the system. The following expression is formulated for the R&D output productivity per FTE researcher working in the system:

- $R_{Paper} / S_{FTE}$ : R&D output rate per FTE researcher person on the system
- $S_{Experience} / S_{HC}$ : average experience stock of the people in the system; and
- $S_{Absorbed} / S_{HC}$ : average absorbed knowledge per person in the system.

A multiplicative model is developed for the development rate of papers per fulltime person working in the system:

$$\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}} = c * \left(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}\right)^a * \left(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}\right)^b \qquad \textbf{9-1}$$

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}}\right) = \ln(c) + a * \ln\left(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}\right) + b * \ln\left(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}\right) \qquad \textbf{9-2}$$

The above expression is thus used to perform the regression for estimating the parameters $a$, $b$ and $c$. The regression analysis executed yielded the following estimates for the parameters:

**Table 9-9: SAS Output for Estimation of the Development of Knowledge**

```
                         The AUTOREG Procedure

                     Dependent Variable    prperfte

                    Ordinary Least Squares Estimates

          SSE                  0.44599109    DFE                       18
          MSE                     0.02478    Root MSE             0.15741
          SBC                  -12.162568    AIC               -15.296135
          Regress R-Square         0.5784    Total R-Square        0.5784
          Durbin-Watson            2.3068    Pr < DW               0.5945
          Pr > DW                  0.4055
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                    Q and LM Tests for ARCH Disturbances
```

| Order | Q | Pr > Q | LM | Pr > LM |
|---|---|---|---|---|
| 1 | 0.2084 | 0.6481 | 0.1093 | 0.7409 |
| 2 | 1.3994 | 0.4967 | 1.4322 | 0.4887 |
| 3 | 3.5987 | 0.3082 | 2.3405 | 0.5048 |
| 4 | 7.0608 | 0.1327 | 10.3345 | 0.0352 |
| 5 | 7.7103 | 0.1729 | 10.4443 | 0.0636 |
| 6 | 8.4556 | 0.2066 | 11.4023 | 0.0767 |
| 7 | 9.8622 | 0.1965 | 11.4473 | 0.1203 |
| 8 | 10.0637 | 0.2606 | 13.2544 | 0.1034 |
| 9 | 10.2928 | 0.3273 | 14.3887 | 0.1092 |
| 10 | 10.4760 | 0.3998 | 17.8694 | 0.0572 |
| 11 | 11.6565 | 0.3900 | 18.3951 | 0.0729 |
| 12 | 12.1879 | 0.4307 | 19.1378 | 0.0853 |

Phillips-Ouliaris
Cointegration Test

| Lags | Rho | Tau |
|---|---|---|
| 1 | -22.3665 | -5.1370 |

| Variable | DF | Estimate | Standard Error | t Value | Approx Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | 0.4779 | 0.1193 | 4.01 | 0.0008 |
| absperhc | 1 | 0.6672 | 0.2013 | 3.31 | 0.0039 |
| expperhc | 1 | 2.1522 | 1.6392 | 1.31 | 0.2057 |

The following section summarises the statistical analysis conducted to estimate model parameters. For details on the tests, see section **Error! Reference source not found.**

The R-Square 0.5784 statistic indicates that the model accounts for 57% of the variation of the percentage time spent by staff on R&D activities. The variable absperhc included in the model is highly significant (p = 0.0039), while Expperhc also illustrates a significance level of 0.2057.

The Durban Watson test statistic was used to gauge autocorrelation use. This statistic is 2.3068 with (Pr < DW = 0.6945 > 0.05 and (Pr < DW = 0.4055) < 0.95, which indicates that the model does not have autocorrelation.

A colinearity test was also conducted on the data, which indicated that all the condition indexes from the regression model were much smaller than 30. It can therefore be concluded that no colinearity is present.

The heteroscedasticity test (Q and LM test for ARCH disturbances) is only interpreted up to two time lags. The probability for arch disturbances in the model for lags one and two are larger than 0.05. We can therefore conclude that the modelled relationship does not suffer from heteroscedasticity.

The Phillips-Perron test was used to gauge stationarity, which indicated that all variables included in the model are non-stationary. After fitting the model, it was tested for stationarity. The test proved that the model residual is stationary and that the variables are cointegrated, which ultimately indicates that the regression is not spurious.

The following table summarises the variable values as well as the variance introduced into the parameter in the model. The variance of the parameters is set equal to the standard error as reported in the SAS output.

**Table 9-10: Estimated Parameters for Knowledge Production**

| Parameter | Estimate | Variance (s.e) |
|---|---|---|

| | | |
|---|---|---|
| Intercept (d) | 0.4779 | 0.06332 |
| Absperhc (a) | 0.6672 | 0.21447 |
| Expperhc (b) | 2.1522 | 1.6 |

When using these parameters with the variance values in the model, the model yields the following output for the development of scientific output (measured in terms of scientific papers):

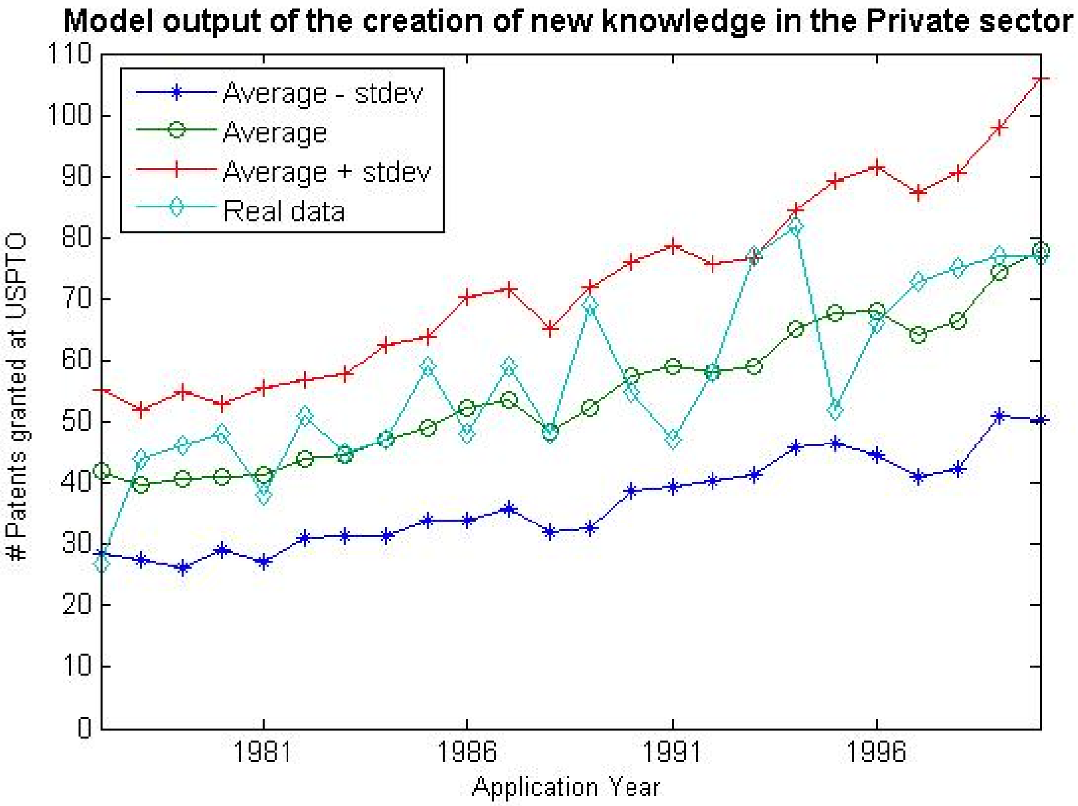



**Figure 9-8: Model Output of the Creation of Knowledge Trend Data**

The coefficient of the determination ($R^2$), i.e. the fraction of the variance in the data explained by the model, is calculated at 0.600349, which indicates that the average of the model runs explain approximately 60% of the variation in the actual data.

Recalling the development of the conceptual model, it was hypothesised that the creation of knowledge can only exists in the presence of the absorption of knowledge. The following section thus deals with the development of a model for the absorption of knowledge subsystem in the model.

### 9.4.2.2 Absorption of knowledge

A regression analysis was used to develop the following model for the absorption of knowledge into the system. The rate at which the system is able to produce new knowledge output is calculated by the contribution made from different stocks in the system. The following expression was formulated for the R&D knowledge absorption rate in the system:

- $R_{Absorptionr}$ : absorption rate of knowledge in the system
- $S_{R\&Doutput} * S_{FTE}$ : R&D output stock interacting with the presence of fulltime equivalent people who can draw on the stocks of knowledge person in system; and
- $S_{World} / S_{HC}$ : available external knowledge stock per headcount personnel employed in the

system.

A multiplicative model was developed for the absorption rate of human resources in the system:

$$\frac{R_{Absorptionr}}{R^*_{Absorption}} = f * (\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}})^d * (\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}})^e \quad \textbf{9-3}$$

This expression is linearised by taking the log-linear form:

$$\ln(\frac{R_{Absorptionr}}{R^*_{Absorption}}) = f + d * \ln(\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}}) + e * \ln(\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}}) \quad \textbf{9-4}$$

This expression was used to perform the regression for estimating the parameters $d$, $e$ and $f$. The regression is executed and yielded the following estimates for the parameters:

**Table 9-11: SAS Output -Estimation of Model Parameters (Absorption of Knowledge)**

```
                               The REG Procedure
                                Model: MODEL1
                          Dependent Variable: arperfte

                     Number of Observations Read          21
                     Number of Observations Used          21

                             Analysis of Variance

                                       Sum of           Mean
       Source                 DF      Squares         Square    F Value    Pr > F

       Model                   2      1.32139        0.66069      12.33    0.0004
       Error                  18      0.96424        0.05357
       Corrected Total        20      2.28562

                    Root MSE              0.23145    R-Square     0.5781
                    Dependent Mean        0.50315    Adj R-Sq     0.5313
                    Coeff Var            46.00031

                          Parameter Estimates

                   Parameter        Standard
  Variable     DF   Estimate           Error    t Value    Pr > |t|    Tolerance     Inflation

  Intercept     1    0.17287         0.13506    1.28        0.2168             .             0
  RDFTE         1    0.63387         0.21174    2.99        0.0078    0.92395        1.08231
  wsperhc       1    1.38633         0.29911    4.63        0.0002    0.92395        1.08231

                             The AUTOREG Procedure

                          Dependent Variable    arperfte


                        Ordinary Least Squares Estimates

               SSE                  0.96423696    DFE                      18
               MSE                     0.05357    Root MSE            0.23145
               SBC                  4.02923226    AIC              0.89566494
               Regress R-Square         0.5781    Total R-Square       0.5781
               Durbin-Watson            1.7635    Pr < DW              0.1533
               Pr > DW                  0.8467
  NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
  for testing negative autocorrelation.

                              Phillips-Ouliaris
                             Cointegration Test

                        Lags            Rho           Tau

                           1       -18.6489       -4.0045
```

```
                                        Standard              Approx
Variable        DF       Estimate          Error    t Value    Pr > |t|

Intercept        1         0.1729         0.1351       1.28      0.2168
RDFTE            1         0.6339         0.2117       2.99      0.0078
wsperhc          1         1.3863         0.2991       4.63      0.0002
```

The following section summarises the statistical analysis conducted to estimate model parameters. (For further details on the test, see section **Error! Reference source not found.**)

The Regress R-Square statistic of 0.5406 indicates that the model accounts for 54.06% of the variation in the data. The P-values are highly significant. The F Value also indicates that the model accounts for a significant percentage of the variability in the data (Pr > F = 0.0004).

The Durban Watson test statistic was used to gauge autocorrelation use. The statistic is 1.7635 with (Pr < DW = 0.1533) > 0.05 and (Pr < DW = 0.8467) < 0.95, which indicates that the model does not have autocorrelation.

The colinearity test conducted on the data revealed that all the condition indexes from the regression model are smaller than the critical value. It can therefore be concluded that no colinearity is present.

The heteroscedasticity test (Q and LM test for ARCH disturbances) was only interpreted up to two time lags. The probability for arch disturbances in the model for lags one and two exceeds 0.05. It can therefore be concluded that the modelled relationship does not suffer from heteroscedasticity.

The Phillips-Perron test was used to gauge stationarity, which indicated that all variables included in the model are non-stationary. After fitting the model, its residual was tested for stationarity. The test proved that the model residual is stationary and that the variables are cointegrated, which indicates that the regression is not spurious.

The parameters are thus estimated as defined in the following expression:

$$\ln\left(\frac{R_{Absorptionr}}{R^{*}_{Absorption}}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutpu}} * \frac{S_{FTE}}{S^{*}_{FTE}}\right) + e * \ln\left(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}}\right) \qquad \textbf{9-5}$$

The following table summarises the parameter values as well as the variance introduced into the parameter in the model. The variance is the standard error of the model as reported in the SAS output:

**Table 9-12: Estimated Parameters for Knowledge Absorption Production Function**

| Parameter | Estimate | Variance (s.e) |
|---|---|---|
| Intercept (f) | 0.1729 | 0.1351 |
| RDFTE (d) | 0.6339 | 0.2117 |
| WSperHC (e) | 1.3863 | 0.2991 |

These parameters with the variance values were used in the model. The model yields the following output for the absorption of knowledge measured in terms of references made to prior art in the patents filed at the USPTO.

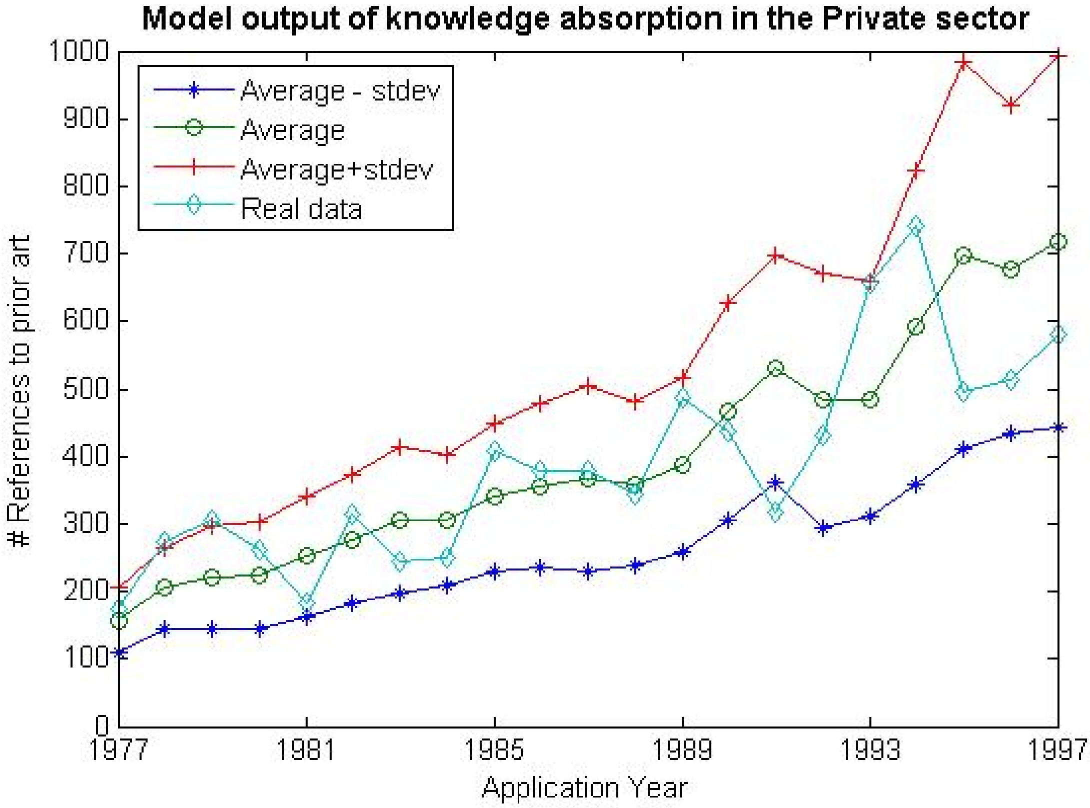



**Figure 9-9: Model Recreation of the Absorption of Knowledge Trend Data**

The coefficient of the determination ($R^2$), i.e. the fraction of the variance in the data explained by the model, is calculated at 0.6409, which indicates that the average of the model runs explains approximately 64% of the variation in the actual data.

## 9.5 Model Simulation and Testing

This section documents scenario tests run on the model. These tests were developed from the research questions as well as the Delphi study conducted. The Delphi study was instrumental in finding the fundamental issues facing the private sector R&D system in South Africa. Using the Delphi study to develop the scenario tests ensured that the scenario tests developed were relevant in terms of the current concerns of experts working in the system.

The following table relates to the scenarios developed in the Delphi study, discussed in more detail in section **Error! Reference source not found.**. The scenario tests run in this section were developed to answer the questions in Table 9-13.

**Table 9-13: The Scenario Tests Runs Executed on the Model**

| |
|---|
| **Base Case:** How would a constant/unchanging investment in the South African private sector R&D system affect its ability to produce R&D output and absorb knowledge? <br><br> **Scenario 1:** How would an increase/decreasing level of investment in the South African private sector R&D system affect its ability to produce R&D output and absorb knowledge? <br><br> **Scenario 2:** How would the introduction of fiscal incentives influence R&D expenditure and the ability |

to produce R&D output and absorb knowledge?

**Scenario 3:** Scenario 3 examines and compares the model's predicted output for different levels of responsiveness from the private sector to tax incentive schemes in conjunction with varying delays of the private sector to react to these incentives.

### 9.5.1 The base case

The base case simulation runs executed on the simulation is firstly aimed at testing the predicted modelled trend in the private sector, should as little as possible change in the system. In other words, the simulation aims to determine what the possible outcome in terms of the development and absorption of knowledge would be if the system continues to exist in an unchanging policy environment,

The following section describes the model output as well as the conclusions that can be reached from the sensitivity analysis:

- the external environment has a 2% increase in knowledge production per year, following recent trends; and
- the R&D expenditure in the sector grows with 0%, resulting in a 0% increase in R&D staff in the private sector.

A normally distributed variability on the parameter values as established in the statistical estimation of the parameters is introduced. The model produces the following output from 100 separate simulation runs executed on the model. In each figure, the average of the 100 runs as well as the trend lines for the standard deviations are shown.

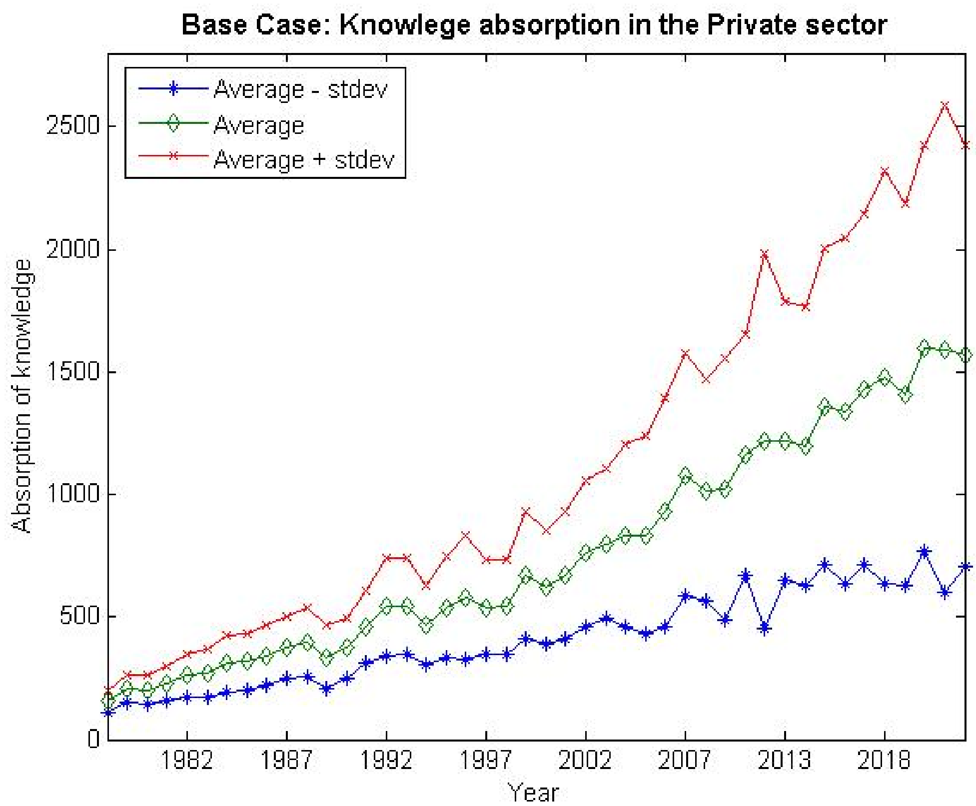



**Figure 9-10 Absorption of Knowledge in the Private Sector under Base Case Conditions**

Figure 9-10 indicates the rate of absorption. It is evident that a substantial increase in the absorption of knowledge can still be expected in the base case. This increase can be attributed to the influence of the external knowledge stock on the system. The system will respond to an increase in the external environment through increasing knowledge spillover and transfer into the R&D system.

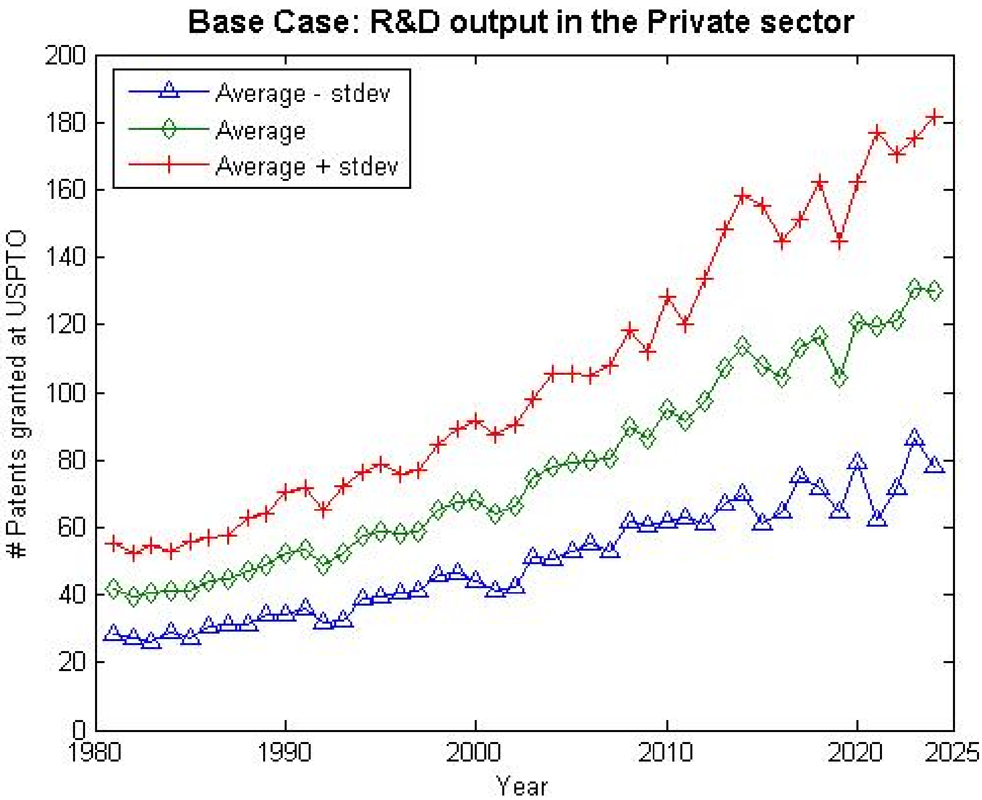



**Figure 9-11 Absorption of Knowledge in the Private Sector under Base Case Conditions**

Figure 9-11 is a graphical representation of the simulation model output for the predicted rate of knowledge creation in the private sector. The model predicts a gradual but continued increase in the number of patents granted. This increase can be attributed to the modelled increase in knowledge in the external environment, resulting in a knowledge spillover and transfer into the R&D system.

#### 9.5.1.1 Base case sensitivity analysis

The model output demonstrates that the model exhibits a numerical sensitivity to variability in the parameters in the system. Model sensitivity in terms of the output of patents registered at the USPTO is evident.

In the base case sensitivity analysis test, the model output illustrates numerical sensitivity to starting values as well as variability in parameters. The graphs all depicts the trend lines for the average calculated from the 100 runs as well as the trend lines for the standard deviation from the average as presented by the model.

The model does not exhibit behaviour mode sensitivity, as the pattern of behaviour is not influenced by the variance introduced to parameters in the system. Under the base case conditions, the model does not show any policy sensitivity, as the changes in assumptions do not reverse the impact of the policy implemented.

We therefore can conclude that although the model is numerically sensitive, no changes in the behaviour of the model as well as the outcome of the policies are evident from model output.

### 9.5.2 Scenario 1

Scenario 1 aims to test model output and predicted system performance under changes in business R&D expenditure. The first scenario test run has the following constants:

- external knowledge creation is increasing at 2% per year following an approximation of recent trends
- salaries remain constant; and
- the system keeps the historical trend of spending in terms of the percentage distribution of funding between labour, capital and running costs.

In this experiment, 100 simulation runs are executed on the model for each of the following scenarios with different rates of increases in R&D expenditure in the private sector R&D expenditure:

**Table 9-14: Test Run for Scenario Testing**

| | Percentage Growth Rate in Private Sector R&D Expenditure |
|---|---|
| Run 1 | -4 % per year |
| Run 2 | -3 % per year |
| Run 3 | -2 % per year |
| Run 4 | -1 % per year |
| Run 5 | 0 % per year |
| Run 6 | 1 % per year |
| Run 4 | 2 % per year |
| Run 5 | 3 % per year |
| Run 6 | 4 % per year |

The average of each of the 100 runs for each of the scenarios was taken. These are presented in the following figure:

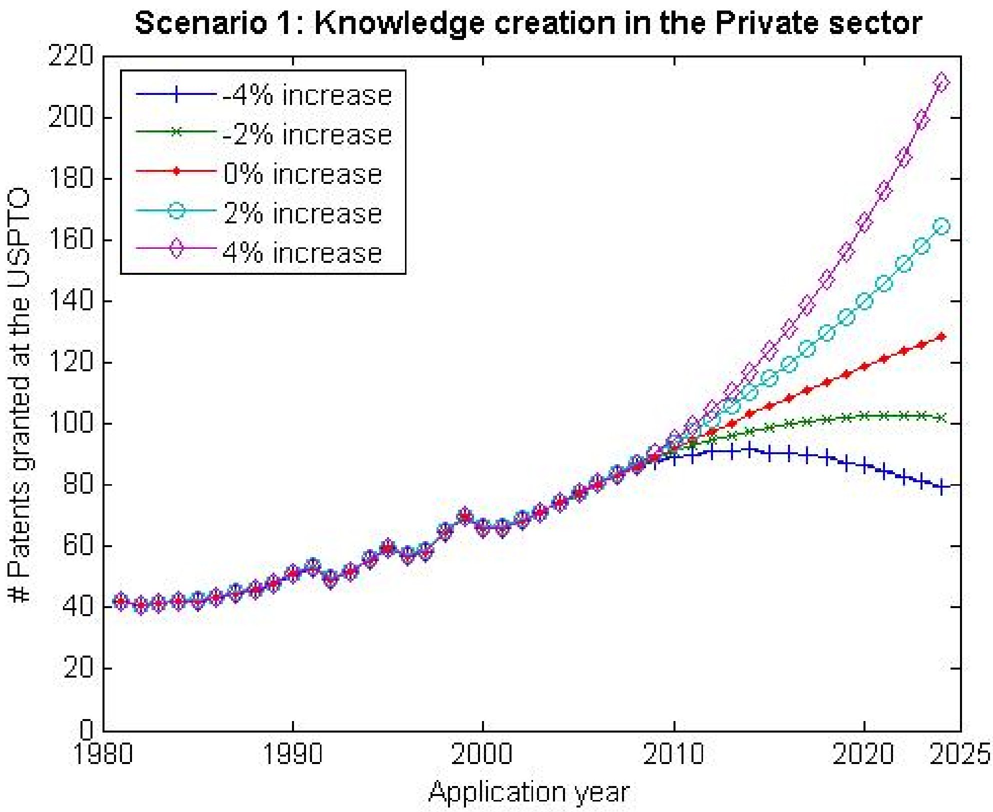



**Figure 9-12 Scenario 1: Knowledge Creation in the Private sector**

It is clear from Figure 9-12 that R&D investment has an effect on the system's R&D output. It can be concluded from the trend that increases in R&D investment should have a positive effect on the creation of new knowledge in the sector. This is in line with what we should expect from system behaviour.

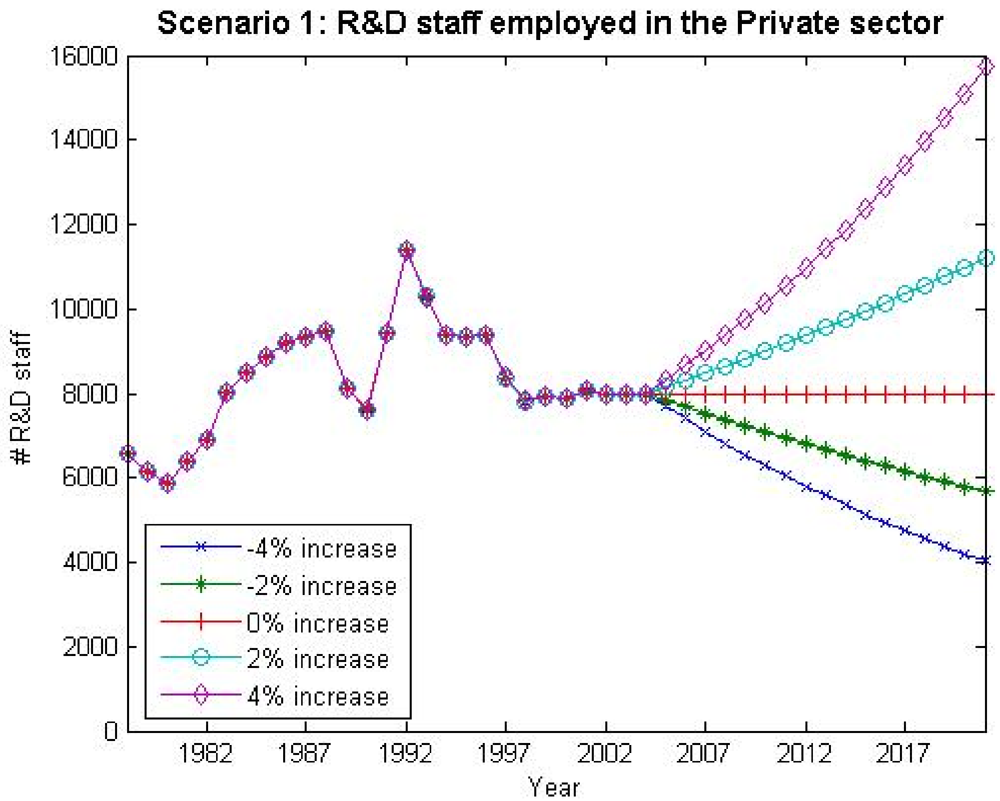



**Figure 9-13 Scenario R&D Staff Employed in the Private Sector in South Africa**

Figure 9-13 is a graphical representation of human resources employed in the system for the different scenario runs. As it is assumed that the increase in expenditure will be in the same percentage distribution towards human resources, running costs and capital as from the past 20 years, the system will also react to the increase by increasing the demand for trained human resources in the system.

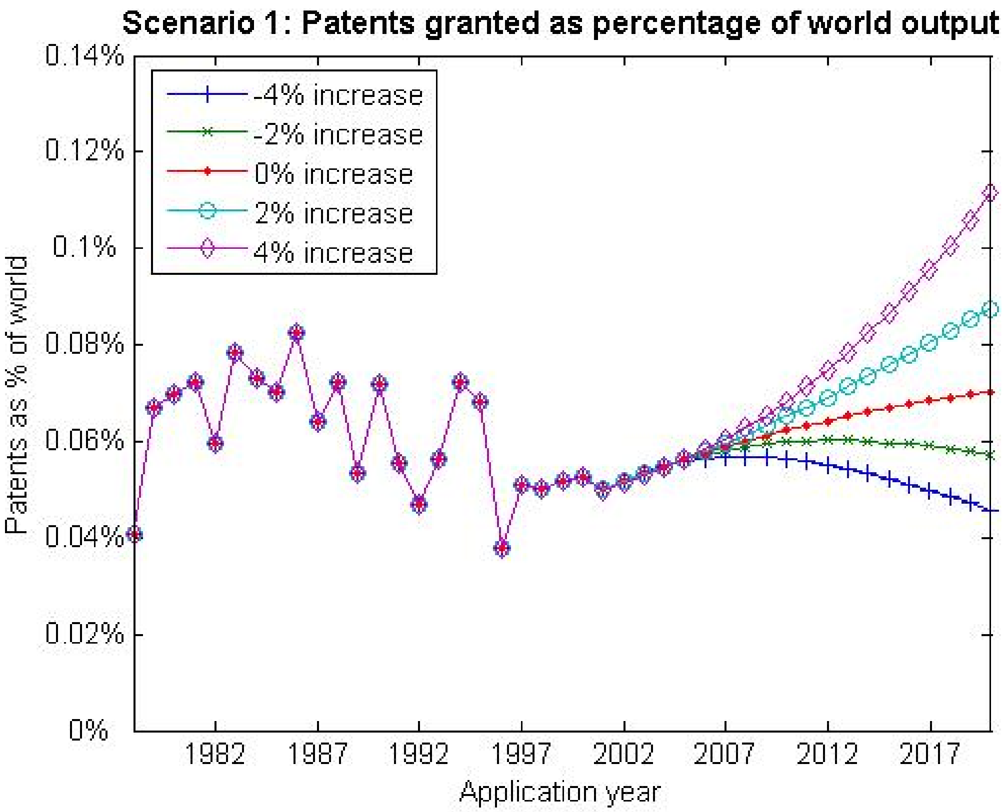



**Figure 9-14: Scenario 1: Output as Percentage of World Output**

An assumption is made that the international growth rate for the creation of new scientific patents will be roughly 2%, following recent trends. The simulation runs yield the results graphically represented in the graph above.

We can therefore conclude that considerable investment will be necessary before South Africa will start to improve its position as an international knowledge creator. South Africa's share of patents filed at the USPTO is extremely low at less than 0.1% and is likely to remain this low despite significant increases in R&D expenditure in the near future

Although the analysis of the system under the different scenarios of increases in R&D spending is interesting, one cannot help but wonder how these increases can be achieved. The following scenario might provide some answers to this question, as it discusses possible system performance under a tax incentive policy.

### 9.5.3 Scenario 2

Pouris (2003) found that the fiscal component of South Africa's system of innovation compared unfavourably to the rest of the world. He states the following consequences:

- local companies as well as multinationals find it more profitable to conduct R&D in countries offering more favourable conditions
- SMMEs find it too expensive to undertake R&D; and
- human resources will find better R&D work opportunities abroad, thus exacerbating the current brain drain phenomenon.

Pouris investigated the possible use of Fiscal incentives to boost R&D spending in the South African R&D system. He analysed the desirability of implementing tax incentives in terms of a net contribution to the welfare of South Africans. He uses a comparison of the social benefit, i.e. gains in the producer and consumer surplus, from R&D induced by the programmes with the associated social cost, comprised by benefit lost by reallocating resources from alternative production, i.e. opportunity cost, resources lost through inefficiencies associated with financing programmes and the transfer of resources abroad resulting from payments made to foreign-owned companies.

Pouris found that an incentive scheme targeted mainly at SMMEs would generate a net social benefit amounting to R373 million to South Africa, whereas a company size neutral scheme could create a net social benefit of R151 million. Pouris therefore holds that funding a tax incentive scheme will benefit South Africa as a whole.

Scenario 2 aims to explore possible system behaviour by testing the outcome of applying fiscal incentives to the system model. The scenario is a test of the effect that the recommendations made by Pouris could have on the South African private sector R&D system.

A very important measure in determining the successful implementation of tax incentives for R&D can be measured by the responsiveness of the private sector to increase R&D spending. Many researchers have found responsiveness to be in the region of unity on the long haul. A responsiveness of unity means that for every 1 dollar lost in revenue, tax incentives produces a dollar increase in reported R&D spending of the margin. The responsiveness is however lower on the short –run, since it takes time for companies to react to such a policy. A dynamic is consequently included to allow for a period for private sector firms to react to the tax incentive. This is modelled by using a first order delay.

It has to be noted that the dynamics included in the model is a highly simplified version of the complexities that can be included in the actual implementation of these policies. The following diagram is a simple representation of the dynamics included to model the effect of fiscal incentives on R&D expenditure in the system.

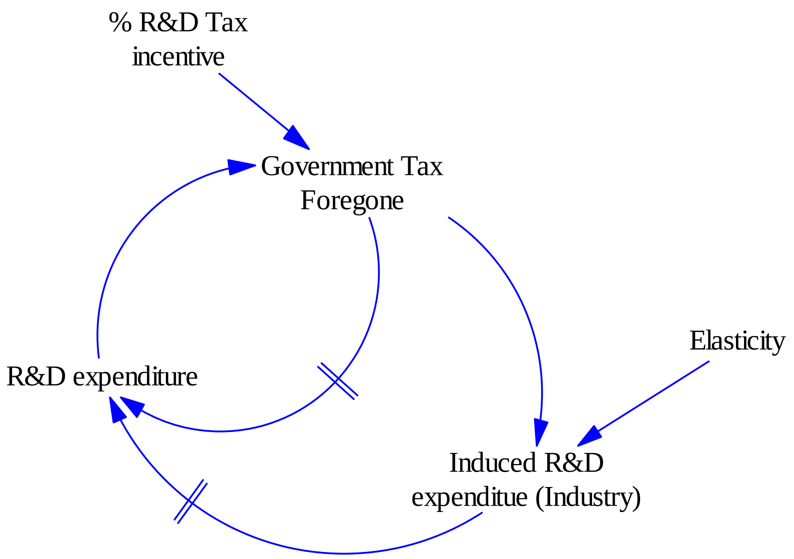



**Figure 9-15: Causal loop of Fiscal Incentive Feedback Dynamics**

The scenario tested is based on a proposed framework by Pouris (2003) for the introduction of fiscal incentives to the South African R&D system. Fiscal incentives were implemented to a total of 20% of private sector R&D expenditure. This will enhance South Africa's fiscal policy environment to enhance its competitiveness with countries such as Australia.

The policy implemented tests model output for the following constants:

- assume base case conditions, thus no growth of the system, only tax incentives
- the tax incentive is started off with a government budget of 10% of R&D, i.e. R200 million
- the process of increasing the government incentives is implemented to increase fiscal incentives to 20% of government R&D expenditure over a five-year period; and
- elasticity is increased from 0 to 1 over a period of time with a number of years (varied from 5 to 15 years) to reach the maximum. This is implemented with reference to literature of many studies where the long-haul effect of R&D fiscal incentives appears to be unity.

**Table 9-15: Delay Values for Simulation runs for Fiscal Incentive Scheme**

| | First Order Delay for Industry to React on Fiscal Incentives |
|---|---|
| Run 1 | 5 years |
| Run 2 | 7 years |
| Run 3 | 9 years |
| Run 4 | 11 years |
| Run 5 | 13 years |
| Run 6 | 15 years |

Figure 9-16 is a graphical representation of modelled industry responsiveness to R&D incentives for different values of first order delays of runs 1 to 6. The scenario tests for different reaction times for industry to respond to tax incentives. The reaction time is modelled as a first order goal-seeking loop.

The response rate of the Business sector to react to the tax incentive will influence the rate at which the R&D expenditure increases. In this scenario, we assume that the eventual (long term) responsiveness of businesses is unity, thus for every R1 in tax revenue foregone, the business sector will spend R1 extra on R&D.

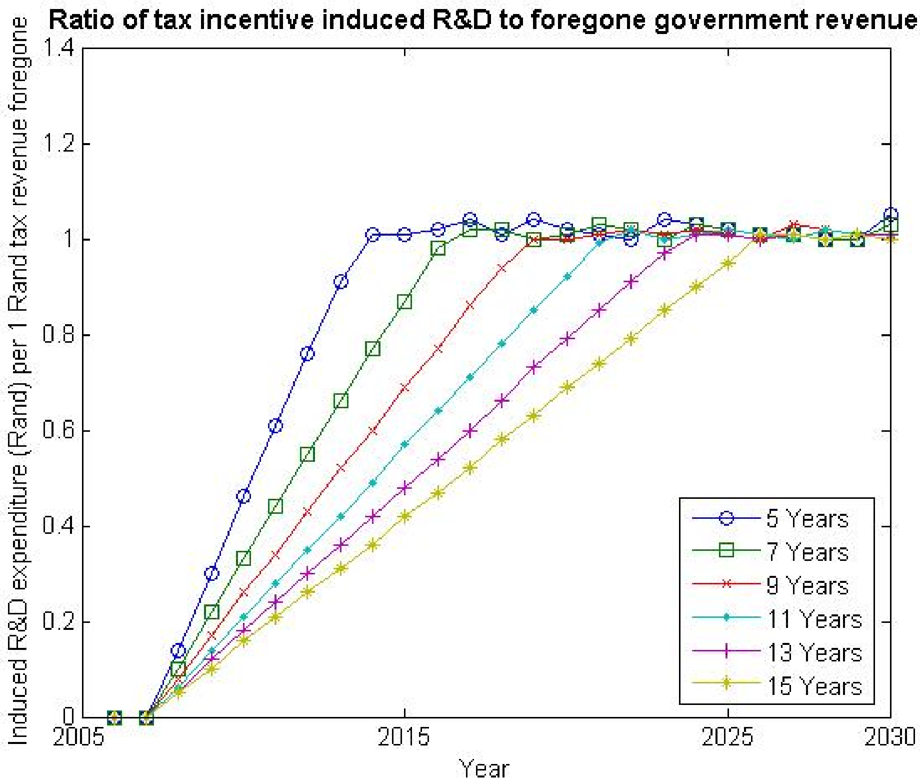



**Figure 9-16: Scenario 2: Ratio of Tax Induced R&D to Foregone Government Revenue**

Figure 9-16 illustrates that for a sorter delay time, private sector firms react to the fiscal incentives quicker to start inducing R&D expenditure in the private sector. The effect of the delay on the system's R&D expenditure is tested.

The firms' reaction to the policy incentives and the induction of R&D expenditure will result in a situation where the business R&D expenditure will increase. The model predicts that the private sector's total R&D expenditure will settle on an eventual increased business R&D expenditure of approximately 50% higher than the initial expenditure on R&D in the sector.

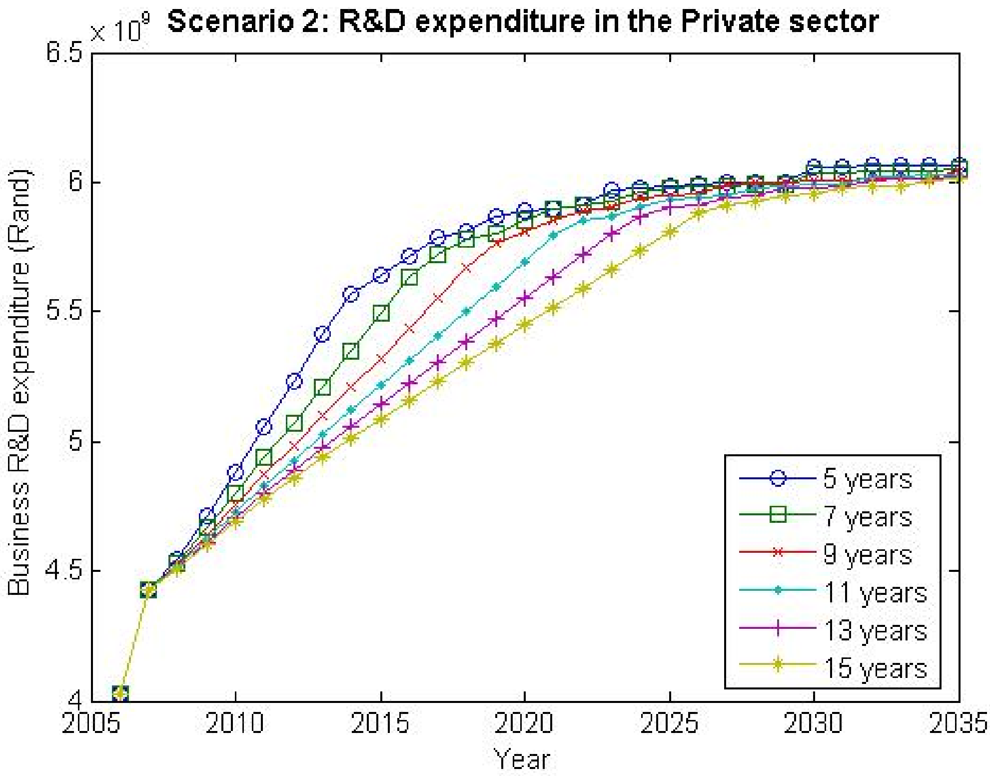



**Figure 9-17:** **Scenario 2: R&D Expenditure in the Private Sector**

An analysis of the trend reveals that despite the reaction time, the eventual increase in R&D expenditure in the private sector is almost 50% higher. This scenario thus illustrates that a slower rate to reach an elasticity of unity does not influence the eventual success of the tax incentive scheme, only the time to reach it. The time period for which the incentive scheme will have to be implemented to ensure success could therefore be a key determining factor of the success of such a scheme.

An assumption was made earlier in this thesis that the distribution of funding remains constant between labour, capital and running costs. As determined earlier, the estimated increase in the business R&D expenditure could result in a 50% increase, should a tax incentive scheme of 20% of business R&D expenditure be implemented. Such an implementation has a direct impact on the amount of people employed in the system, resulting in a 50% increase in human resources.

Questions immediately arise regarding the availability of such an amount of people in the system and whether the system will allow for the amount of trained people. The graphs below depict the expected demand. The above could naturally also influence the time with which the system will be able to react on the fiscal incentives policy.

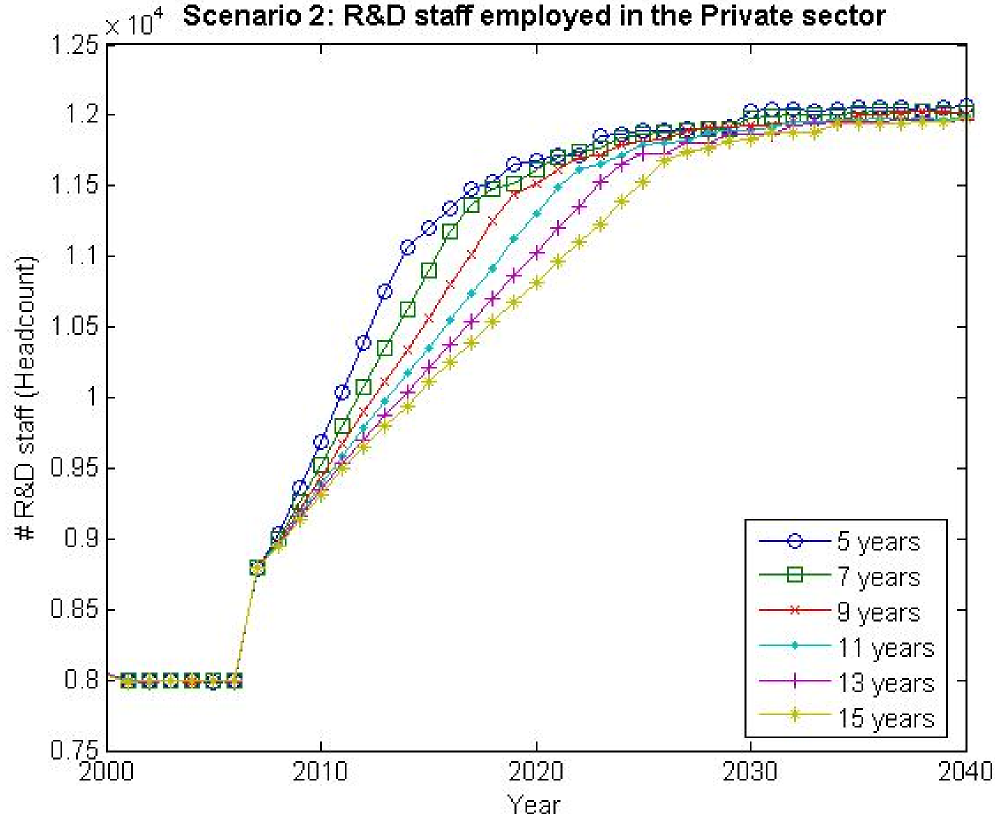



**Figure 9-18: Scenario 2: R&D staff Employed in the Private sector**

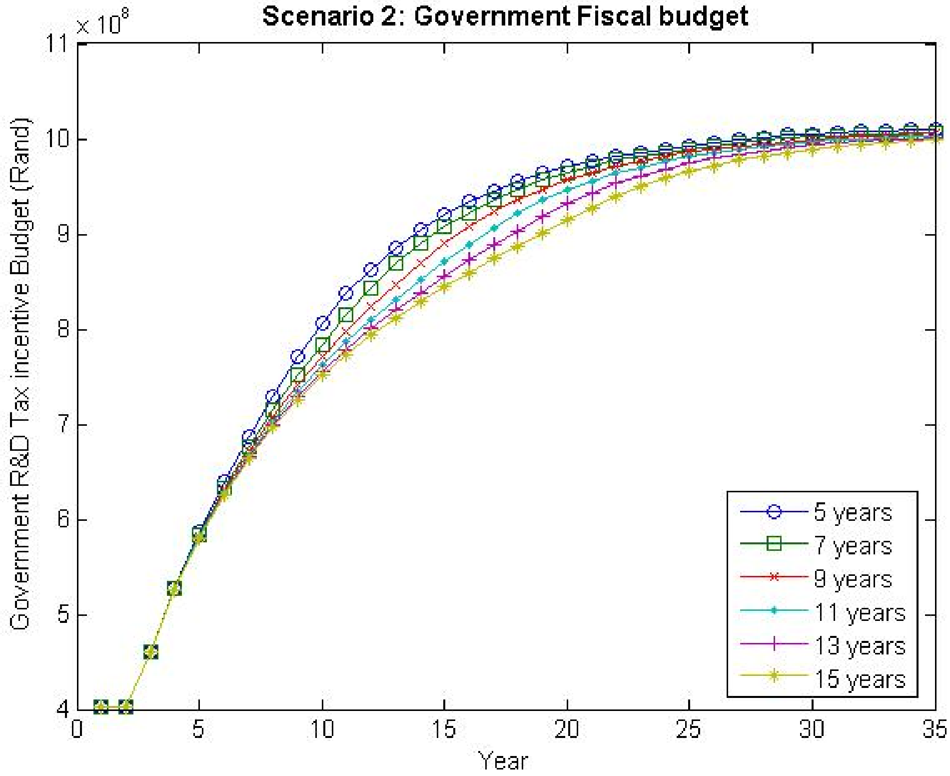



**Figure 9-19: Scenario 2: Fiscal budget anchored at 20% of R&D expenditure**

Figure 9-19 reveals that the Fiscal budget will continue to grow and eventually settle in the region of R1 billion. This growth of the fiscal budget is linked to the value of the starting budget, in this case R400 million, as well as the gradual increase of the system to reach a fiscal government budget of 20% of the R&D expenditure in the business sector. The growth of the government fiscal budget is therefore linked to the growth of the R&D expenditure in business R&D expenditure. The reaction time of companies in the private sector also influences the budget size during the first 30 years.

The scenario test thus holds that R&D expenditure in the private sector can be increased, should the fiscal incentives be implemented successfully . However, we have seen that the increase of 50% will only be possible if the system can sustain the 50% increase in human resources in the system.  Thus an observation naturally lead to questions around the success of the system, should an elasticity of less than unity be achieved. The following section explores these issues in more detail.

### 9.5.4 Scenario 3

Scenario 3 aims to examine and compare the model's predicted output for different levels of responsiveness from the business sector to tax incentive schemes in conjunction with varying delays of the business sector to react to these incentives.

The policy implemented tests model outputs for the following constants:

- assume base case conditions, thus no growth of the system, only tax incentives
- the tax incentive is started off with a government budget of 10% of R&D, i.e. R400 million;  and
- the process of increasing the government incentives is implemented to increase fiscal incentives to 20% of government R&D expenditure over a five-year period.

The effects of changes in the system are tested along two axes:

- Axis 1: change in the private sector responsiveness to tax incentives. The different elasticities are implemented in increments of 0.2 from 0.4 to 1.6. An elasticity of 0.4 would imply that R0.40 R&D expenditure is induced in the business sector for every R1 tax foregone by government;  and
- Axis 2: change in the scenario runs are executed for different responsiveness time delays of 5 - 15 years.

**Table 9-16: Scenario 3: Changes in System Constants along Two Axes**

| | | **Delayed Reaction on Fiscal Policy (in years)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **3** | **5** | **7** | **9** | **11** | **13** | **15** |
| **Elasticity** | **0.4** | | | | | | | |
| | **0.6** | | | | | | | |
| | **0.8** | | | | | | | |
| | **1.0** | | | | | | | |
| | **1.2** | | | | | | | |
| | **1.4** | | | | | | | |
| | **1.6** | | | | | | | |

Each cell in Table 9-16 represents a specific scenario tested for. A total of 100 simulation runs were executed for each of these scenarios (cells) in the above table.  For each of the cells in the grid, 100 simulation outputs were thus created for years 1980 to 2030. To obtain a convenient measure of comparing the different scenarios, the average of these trends was computed by calculating the average value of the trend from the years 2010 to 2030, resulting in a single value that can then be represented in the matrix.

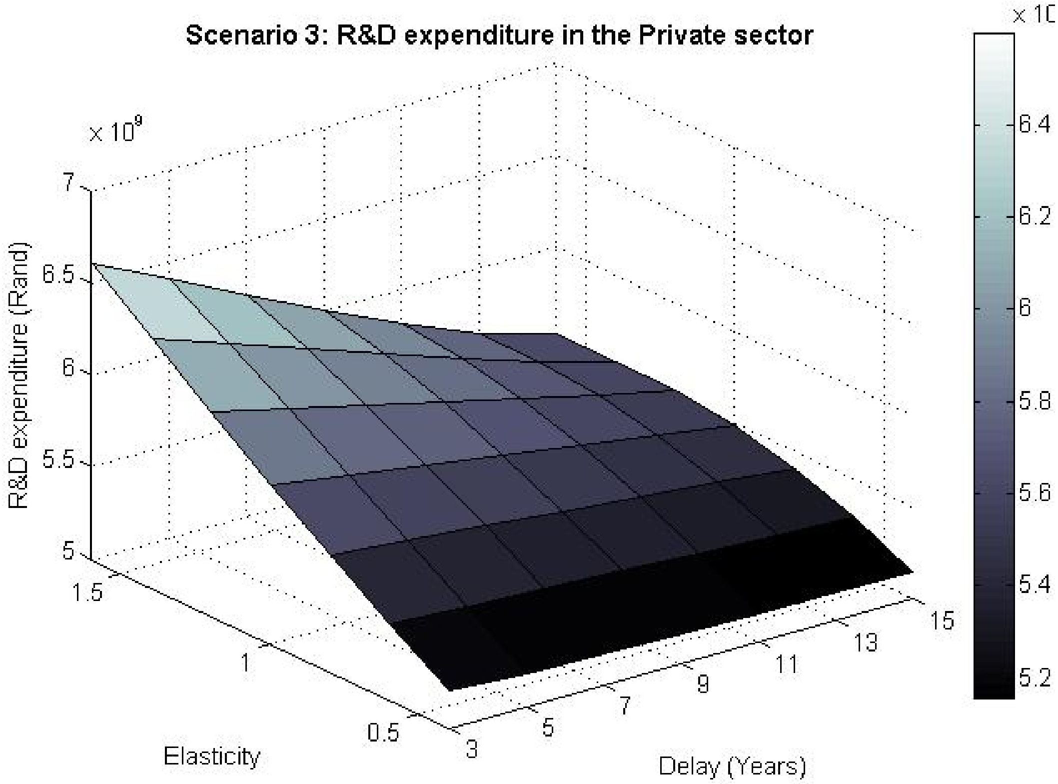



**Figure 9-20 Scenario 3: Total R&D Expenditure in the Private Sector**

Figure 9-20 clearly yields Figure 9-20 that business R&D expenditure could be increased through a strategy of fiscal incentives. The success of the scheme would be influenced by business firms' ability to react on the fiscal incentives scheme within a reasonable amount of time and a high as possible level of responsiveness (elasticity). It is also clear that the success of such a scheme would depend on the continuity of its implementation.

The following figure is a graphical representation of the costs to government in terms of tax revenue to implement tax incentives.

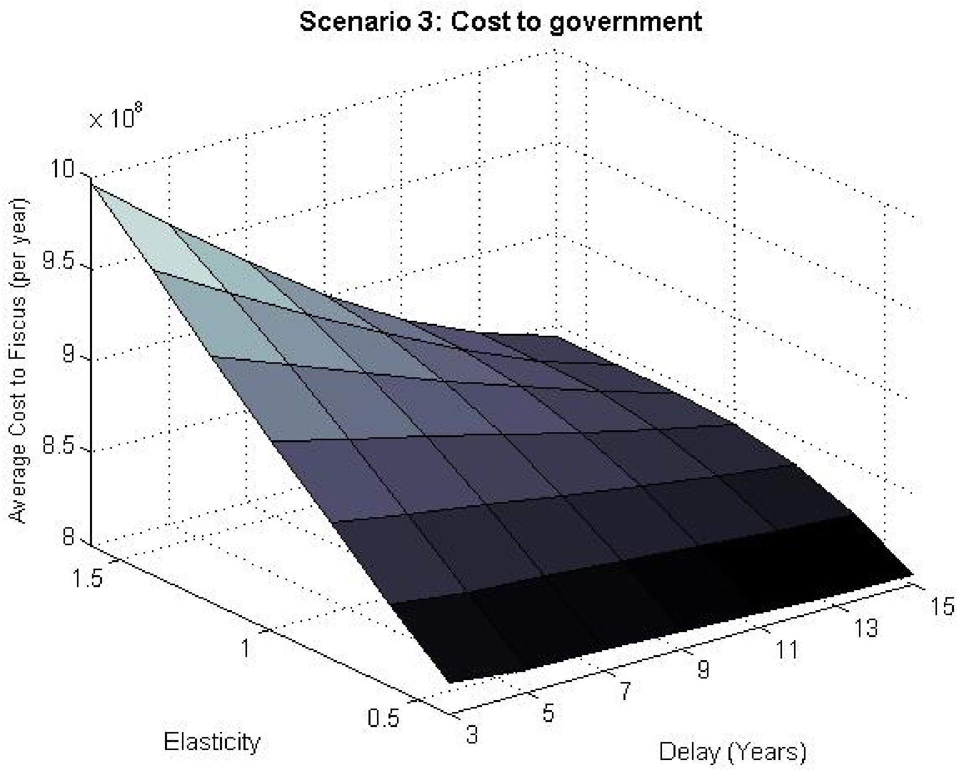



**Figure 9-21:** **Government Contribution in Terms of Tax Breaks**

It is therefore clear that the cost to government will increase for the scenarios where the system reacts with high responsiveness. High responsiveness would imply that the tax incentive policy is successful in inducing higher R&D expenditure in the business sector. If the cost to government is fixed at 20% of business R&D expenditure, the cost to government will continue to rise as business R&D spending increases.

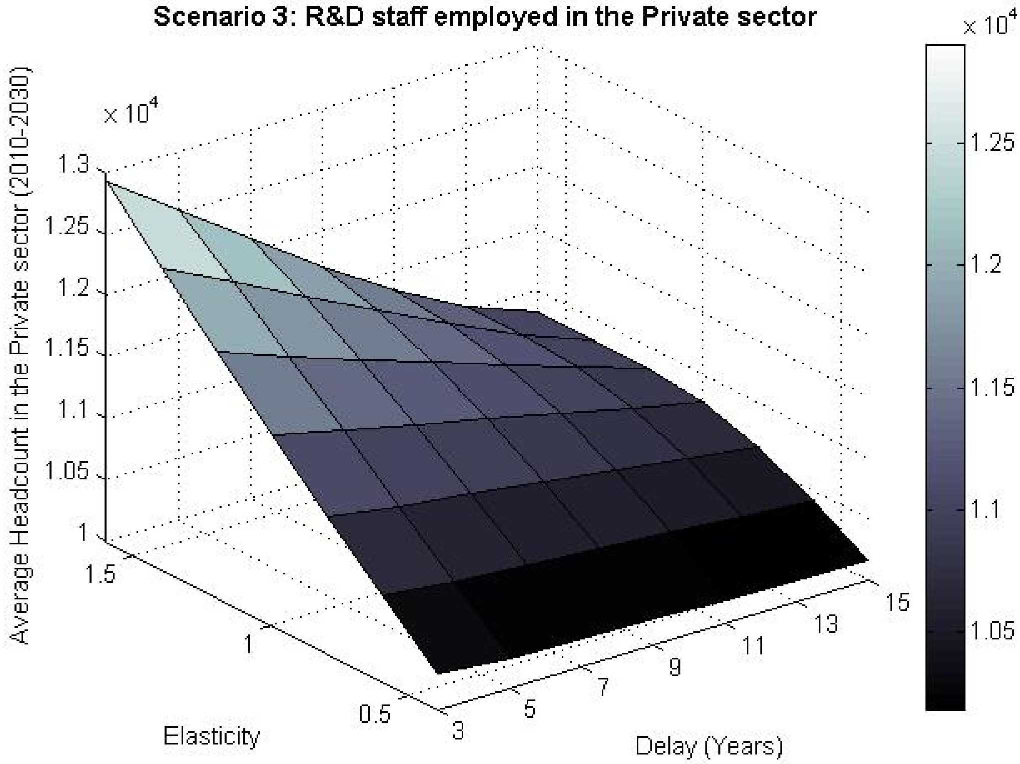



**Figure 9-22: Scenario 3: R&D Staff Employed in the Private Sector**

The increase in the R&D expenditure will also impact on the human resources employed in R&D in South Africa. Figure 9-22 is a graphical representation of the average human resources employed in years 2010 to 2030 in the private sector.

The dynamics adopted in the model assumes a model driven by R&D expenditure. It is however important to keep in mind that the higher expenditure ultimately translates into a larger R&D workforce. This model assumes a steady flow of trained human resources and chooses to ignore any constraint that might exist in terms of finding suitable trained R&D workers.

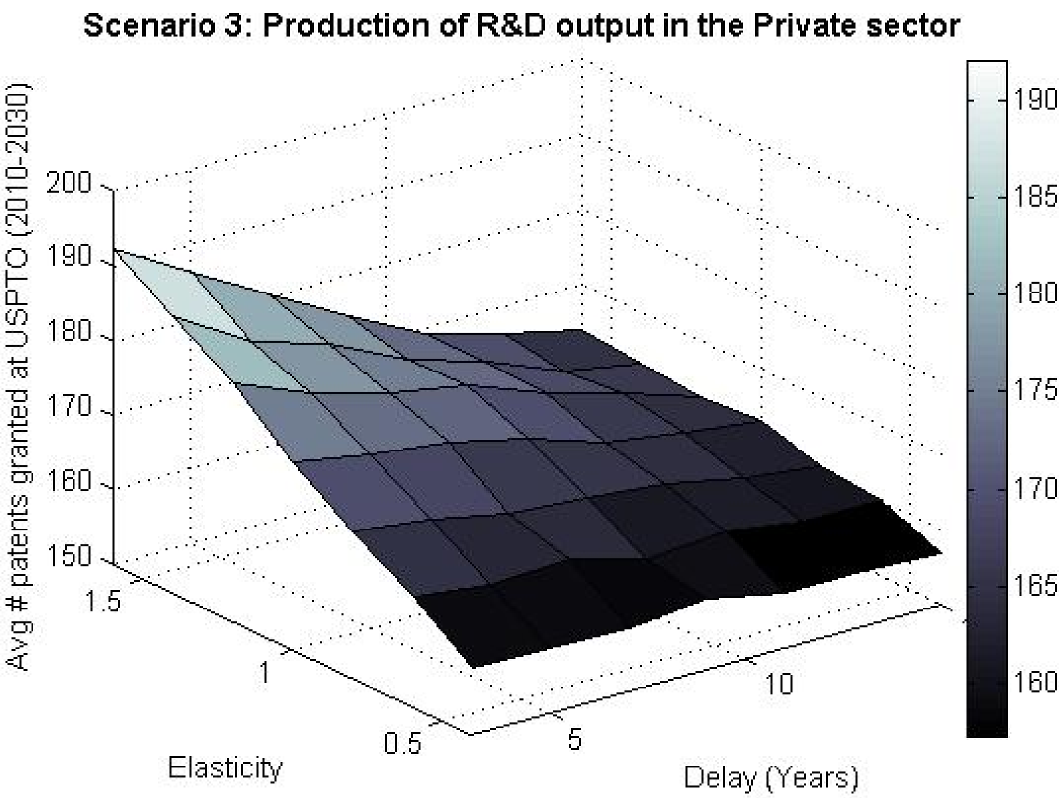



**Figure 9-23: Scenario 3: Average Number of Patents Granted at the USPTO (2010 -2030)**

Figure 9-23 depicts the effect of the different runs on the average patents granted to organisations in the private sector. It is clear that the output obtained from the model does not illustrate a major difference in patents granted. An approximate 18% difference in R&D output between the highest and lowest average output can be observed.

## 9.6 Chapter Summary

This chapter documents the data gathered and the application of a conceptual model developed in Chapter 4 of the R&D system in the South African private sector.

Statistical analysis yielded that the estimation of parameters in the production functions was statistically significant. The explanatory variables included in the model were confirmed to be statistically significant to the explanation of the dependent variables.

The following table summarises the coefficients of determination ($R^2$) of the various regressions in the system dynamic model:

| Dependent Variables | Regress R-Square |
|---|---|
| Patent creation rate | 64% |
| Knowledge Absorption rate | 60% |

We can therefore conclude that the coefficients of determination have satisfactorily high values and the model seems able to explain the most important trends in the actual data. The model was used to run scenario tests uncover possible behaviour of the system under conditions specified in the scenario tests.

The base case scenario yielded that should the system be left unchanged in terms of the distribution of the funding as well as the R&D expenditure (in 2003 Rand), the model predicts a small but gradual increase in the number of patents granted. Such an increase can be attributed to the continued increase in knowledge in external environment, resulting in knowledge spillover and transfer into the R&D system.

Scenario 1 tested the influence of increased/decreased R&D expenditure in the private sector. The tests revealed that the knowledge creation output rate will increase as an increasing number of research staff is employed in the system and as the knowledge stocks in the system increase.

Scenario 2 explored possible system behaviour by testing the outcome of applying fiscal incentives on the system model. The scenario was a test based on the recommendations made by Pouris (2003). This scenario concluded that a slower rate to reach an elasticity of unity does not influence the eventual success of the tax incentive scheme, only the time to reach it. The time period for which the incentive scheme will have to be implemented to ensure success could be an important determining factor of the success of such a scheme.

Scenario 3 aims to examine and compare the model's predicted output for different levels of responsiveness from the business sector to tax incentive schemes in conjunction with varying delays of the business sector to react to these incentives. Two constants in the model are changed along two axes:

- Axis 1: change in the private sector responsiveness to tax incentives. The different elasticities are implemented in increments of 0.2 from 0.4 to 1.6. An elasticity of 0.4 would imply that R0.40 R&D expenditure is induced in the business sector for every R1 tax foregone by government; and
- Axis 2: change in the scenario runs are executed for different responsiveness time delays of 5 to 15 years.

A strategy of fiscal incentives would result in an increase in business R&D expenditure. The success of the scheme would be influenced by business firms' ability to react on the fiscal incentives scheme within a reasonable amount of time and a high as possible level of responsiveness (elasticity). It is also clear that the success of such a scheme would also be dependent on the continuity of its implementation.

This chapter discussed the application of a conceptual model of R&D on the South African private sector. The following chapter provides a detailed discussion of the validation and criticisms on the model.

# 10 CONCLUSIONS AND RECOMMENDATIONS

## 10.1 Overview

The NSI perspective is a recent paradigm of studying innovative activities. The NSI approach accentuates the systemic nature of complex systems with feedback loops and elements. Most studies on NSI's tend to be descriptive and therefore fail to capture the dynamic behaviour of the system. This is also the case with the existing models dealing with the South African system of innovation. These models are not equipped to capture the dynamic characteristics of the system or to simulate the long-term effects that changes to R&D policy might have on the system.

The main research question in this thesis is to find a way of estimating the effect that investment in R&D or the lack thereof might have on the South African R&D system's ability to develop R&D output and to absorb R&D related knowledge.

The purpose of the model was to model and explain the effect that the presence/lack of long-term investment in R&D and R&D resources could have on the system's ability to produce new knowledge as an output.

The contribution made in this thesis is that the development of a system dynamics model of the development of R&D output in South Africa will create a tool for the analysis of the effect of R&D spending on the system's capability to produce R&D output.

## 10.2 Thesis outline summary

The strategy followed in the research project was firstly to develop a conceptual systems dynamic model of R&D from an NSI perspective. Following the development of the conceptual model, it was applied to the three R&D sectors identified from the Frascati manual, namely:

- HES
- public sector; and
- private sector.

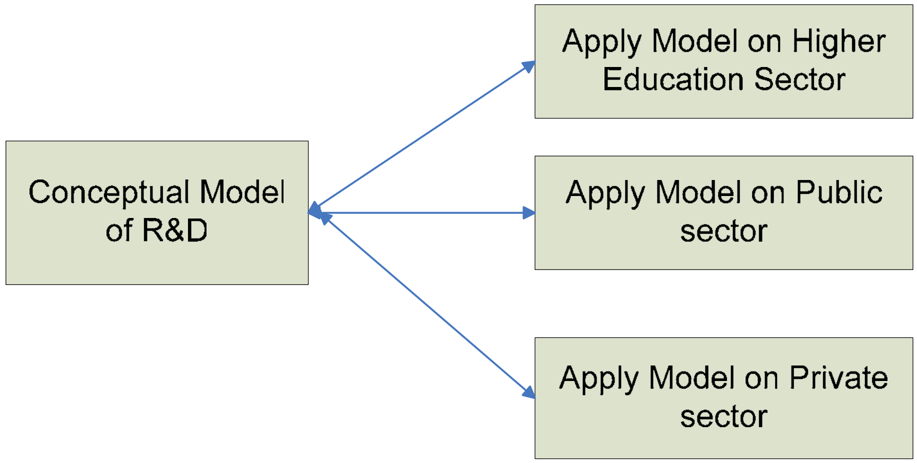



**Figure 10-1: Application of Conceptual model to R&D sector**

When developing the model, it was attempted to apply the attributes of a good model (Kirkby, 1996):

- the conceptual model developed was developed specifically with the intention to be *scaleable* to an R&D performing sector
- the difficulty to have a *physical basis* is due to the nature of the system and the concepts being modelled. Many of the concepts incorporated in the model are intangible and difficult to quantify. These intangible concepts were quantified using indicators. It was also attempted to base the development of the conceptual model on the theory of knowledge creation and absorption, including important aspects of learning and forgetting
- attempts were made to keep the *model structure* as *simple* as possible; and
- the application of the conceptual model on the different sectors, i.e. HES as well as public and private sector, is seeking to provide a measure in which the model can be *generalised*.

The following sections discuss and describe the conclusions drawn from tests as well as the validation of the application of the conceptual model to the R&D sectors. Firstly, various general conclusions regarding all three instances of the application of the model to the HES, public and private sectors are made, followed by discussions focussing on the individual application of the model to each of the three sectors modelled in the research project.

### 10.2.1 General conclusion

**Structure assessment**

The first step in the development of the model structure was the development of the causal loop diagram. This diagram was derived after a thorough investigation into the theory of R&D and knowledge creation. Interviews and discussions with experts on the South African R&D system as well as modelling experts yielded that a system structure revealing delays in the system are important. This applies specifically to the delay inherent to the development of an R&D capacity in human resources. An attempt was made to include the effect that experience, R&D output and the level of absorbed knowledge (learning) in the system might have on human resources' ability to create R&D output and to absorb knowledge from the external environment.

The level of aggregation of the model is on the sector level (HES, public sector and private sector). This is an accumulated level of all organisations and science fields in the specific R&D sector. It must however be admitted that the level of aggregation might be more revealing on a research field level or on an organisational level.

There are many problems obstructing the analysis on a more detailed level. This is especially an issue in terms of the availability of data and the nature of the aggregation of data from different data sources. An example of these difficulties faced is that R&D spending data is aggregated and categorised in different scientific fields for different years.

Furthermore, although the percentage spending for specific scientific fields might be available from the R&D surveys as grand totals, no further data in terms of the finer details, such as salaries and the percentage time spent by human resources working in these respective fields is available on this level of aggregation. The main reason for the inability to conduct this analysis on a more detailed level is thus that the data is either not available on that level or that time series data is totally incompatible in terms of the level of aggregation and the classification of science fields with each other.

Care was also taken to ensure that the model structures conform to basic conservation laws in the flows between stocks:

- conservation of people in the ageing chain: the ageing chain dynamic ensures the conservation of the human resources until they leave the stocks through the modelled attrition
- conservation of experience in the co-flow structure: the experience associated with the human resources in the system also complies with the laws of conservation; and
- knowledge stocks: a relatively simple stock structure is followed in the different knowledge stocks in the system. This stock has simple inflows, as knowledge is created or absorbed, and outflows, when knowledge becomes obsolete. The dynamics of these stocks were confirmed to conform to conservation laws.

By applying the model on the aggregate level of a sector, the issue of geographical proximity is ignored.

An attempt was made to consider the complexity inherent to social systems and the unpredictability inherent to human behaviour. A normally distributed random component is thus introduced to system parameters as well as in delays in the system. To estimate the effect that the random component in the parameters might have on the system, behaviour is tested and discussed in more detail in model sensitivity analysis tests.

**Dimensional consistency**

The models were checked for dimensional consistency through inspection and the dimensional analysis software built-in facility of the STELLA software package. The dimensional consistency check was conducted and the model was confirmed to be dimensionally consistent.

Furthermore, a strategy of normalisation of variables was followed to calculate production functions in the model. This also enhanced the ease with which the model could be made dimensionally consistent. Normalisation causes the effect that a change one stock has on the rate of change of another one to become dimensionless (reflected as a percentage change from the reference value).

**Boundary adequacy**

Model boundary charts are developed for each of the applications to the sectors, as various alterations were made to the conceptual model in the application of the model to the sectors. These aspects are discussed in more detail for each sector.

**Model behaviour in extreme conditions test**

Extreme condition tests were executed on the calibrated model after applying the model to the R&D sectors. The outcome of this test is therefore discussed for each sector individually.

**Integration error test**

The models for all three sectors were tested for sensitivity to the size of the time step used. The model simulations were run for a halved time step. The output of the simulation results yielded similar results to what was achieved with a larger time step. The conclusion was therefore drawn that the model is not sensitive to changes in the time step size.

**Family member test**

The model was applied to the South African HES as well as public sector and private sector. By applying the conceptual model to the different R&D sectors in the South African NSI, the model was also tested for its generaliseability. The following sections discuss these models in more detail.

### 10.2.2 Conclusions: HES

#### 10.2.2.1 Model validation and criticisms

**Structure assessment**

Section 10.2.2 mentioned the unavailability of data for a successful application of the conceptual model on a more detailed level than the R&D sector level.

To apply the model on a group of organisations that will provide an adequate approximation of the R&D activities in the HES, the conceptual model was applied to a group of universities known as HAUs. This group of universities produces approximately 92% of scientific output (journals publications) generated in the HES. Since they contribute a very small percentage of the R&D output in South Africa, the HDUs and

Universities of Technology, formerly known as technikons, are ignored for the purpose of this analysis.

Although care was taken to exclude universities with little or no research output, there are differences in the R&D output productivity, time spent by researchers on R&D and student-to-staff ratios within the group selected for analysis. It must therefore be admitted that the level of aggregation might be more revealing on a university level rather than the aggregate. The same is also true for R&D productivity between academic and research personnel within universities.

Another issue regarding the analysis's level of aggregation is that the analysis is applied on the aggregated level of all research fields in the system. Once again, it could be more revealing to apply the conceptual model on a research field level. This could result in a better representation of the actual system (e.g. people generating knowledge in chemistry seldom makes use of knowledge created in the human sciences and vice versa). The model employs knowledge stocks that could have been more accurate representation of reality if aggregated on a level of different science fields. An example of such an analysis is a study done by Pouris (2006), where he used scientific publications data on scientific field level to identify centres of excellence in the University of Pretoria. The main reason an analysis could not be conducted on this level is that the time series data is either unavailable or entirely incompatible in terms of the level of aggregation and the classification of science fields with each other, especially across different sources and over the time period 1979 to 2001.

It should therefore be noted that the author is well aware of the shortcomings in the application of the conceptual model to the HES in terms of the chosen level of aggregation.

The analyses of the system on its aggregate also hold some advantages. The HES is analysed as a whole, resulting in the analysis being simplified by not populating and calibrating the model for a number of science fields or organisations. The simplified analysis can also aid in using the application of the model to the HES as a policy tool. Analysing the system on the National level ensures that the system is analysed as a whole, enhancing the explanatory value of the model. This also focuses attention on the most important flows in the system without getting lost in the details of a more complicated analysis.

### Boundary adequacy

To obtain a better idea of the adequacy of the model boundary, the following model boundary chart was developed for the HES model:

**Figure 10-2 Model boundary chart of the HES R&D system model**

| Endogenous | Exogenous | Excluded |
|---|---|---|
| Absorptive capacity - rate of absorption of external knowledge | Rate of world knowledge creation | Change in national priorities |

| | | |
|---|---|---|
| Performance of R&D - productivity of producing R&D outputs | Researcher career span - average retirement age | Racial demographics of human resources stock (can be included) |
| HR knowledge stock (experience stock) | Students in the system – from HEMIS | Institutional research culture |
| Influence external knowledge has on absorptive capacity | Average knowledge life time - estimated from data | Attitude of academic and research staff towards R&D |
| Influence of HR and FTE on the system's ability to absorb knowledge | Salaries of R&D workers (used to compute the number of people employed for a specific spending) | The positive effect training more student might have on the availability of R&D workers |
| Influence of absorbed knowledge on system | Growth rate of R&D workers' salary in the system | Productivity differences between academic and research staff |
| Influence of previous R&D experience and ability to produce output on absorptive capacity | Employment of researchers (steady supply stream of R&D personnel) | Influence of school and university system on availability of R&D workers |
| Percentage time spent by the average researcher on R&D activities | | Type of students (Science, Engineering, Human Sciences) |
| | | Effect of geographical proximity |

A crucial assumption made in the application of the model is that the model is driven through funding. The model assumes a steady flow of trained human resources into the system.  For simulation purposes, the model thus ignores the effect that restrictions on the availability of human resources might have on the provision of academic and research staff to the system. These issues are only taken into consideration when considering the effect of funding on the amount of human resources employed in the system. From the model's reaction to increased funding, policy makers will have a clear indication of what its effect on the demand for human resources will be as a result of increased funding.

The connection between training students to the availability of trained scientists and engineers on the system is also ignored. This again assumes a steady supply of human resources. From the model output, the model provides an indication of the human resources that will be employed in the system at a specific R&D expenditure rate. The effect of the secondary education system on the availability of students to the system and the fields of study of the students are also ignored. Conclusions are however drawn from the system's demand for trained human resources as expenditure increases, also stating the implications of the increased funding on the human resources employed in the system.

**Model behaviour in extreme conditions test**

Extreme condition tests have been executed on the model.  The following is a short description of the most important tests performed:

*Test 1: The academic and research staff in the system drops to 0 in the year 2004*

*Expected reaction of system:* This should result in a zero headcount employed in the system, causing knowledge stocks, i.e. R&D knowledge stock and absorbed knowledge

stock to decay to a zero level.
*Outcome:* The system exhibits the expected behaviour.

*Test 2: The percentage time that academic and research staff spends on R&D drops to 0 in 2004*
*Expected reaction of system:* The FTE research staff drops to zero, resulting in a nill rate of absorption of knowledge and the creation of knowledge. The knowledge stocks continue to decay. If the situation persists, the knowledge stocks become completely depleted.
*Outcome:* The system exhibits the expected behaviour.

*Test 3: World knowledge stock drops to 0*
*Expected reaction of system:* The rate at which the system absorbs knowledge starts decaying as the world knowledge stock starts decaying. This eventually influences the rate at which the system produces knowledge. The system also decays after a period, as it is influenced by the lack of the creation of knowledge in the external environment.
*Outcome:* The system exhibits the expected behaviour.

The modeller is satisfied that the model reacts to the extreme condition tests in a satisfactory way.

**Parameter assessment**
The parameters chosen and tested for in the model is discussed in some detail in the data gathering and analysis chapter.

The parameters and constants chosen in the distribution of funding are computed from the historical trends in the R&D survey and HEMIS data. These trends revealed that the percentage expenditure distribution was relatively constantly distributed between labour (50%), capital (5%) as well as running and other costs (45%).

The parameters estimated for the distribution of the percentage hiring decisions across the ageing chain was estimated and then accepted on the basis of the recreation of the ageing trend observed in the HES's human resources.

The parameter assessment in terms of the production functions for the development or creation of new knowledge and the absorption of knowledge was done by selecting two regression models:

- production function 1: development of knowledge, measured in scientific papers produced in the HES; and
- production function 2: absorption of knowledge, measured in the amount of citations made form scientific papers created in the HES.

After trying various regression models, the final model was selected on the basis of the dynamics in the system, an acceptable coefficient of determination ($R^2$) and the significance of the parameters included in the regression model. All the variables included in the model proved to be highly significant and the selection was made for a significance level of 5%.

Care must be taken with the interpretation of predicted results obtained from the model, as the time series data on which the regression was performed spanned only 20 years (only 20 data points was available), which could contribute directly to the over or underestimation of some of the parameters.

The models were tested rigorously for colinearity, heteroscedasticity and autoregression as well as spuriousness in the modelled relationship i.e. stationarity. The outcome of the tests proved satisfactory and the modeller is satisfied that the necessary tests were conducted successfully. It was therefore decided to employ these relationships until more data points or a more appropriate model is available.

**Behaviour reproduction**

The most important behaviour reproductions in the HES model are discussed in this section.

It can be concluded that the ageing trends seen in the HEMIS data are recreated in the model's human resources subsystem. A general ageing of the academic and research workforce is evident. Many researchers have observed and documented this trend. It has also been mentioned in government policy reports as an area of concern (NACI, 2002), (DACST, July 2002).

The point-by-point fit of the model for the rate at which the system produces new knowledge (scientific output) as well as the rate at which the system absorbs new knowledge is estimated in the SAS package. This is also presented in the sections where model parameters are estimated. The model output simulation runs and the model's ability to reproduce history are compared to model output in the simulation test runs:

- the output for the development of scientific output, measured in terms of scientific papers, yields a coefficient of determination ($R^2$) of 0.85087. The model thus explains 85% of the variation in the actual data; and.
- the output for the development of absorption of knowledge, measured in terms of references made to scientific papers, yields a coefficient of the determination ($R^2$) of 0.93. The model thus explains 93% of the variation in the actual data.

This section therefore concludes that the most important trends are recreated with an acceptable level of accuracy. The following section discusses the predicted output of what-if scenario tests and policy tests on the model.

### 10.2.2.2 Summary of results

A relationship between the rising student-to-staff ratio and a decrease in the percentage time that academic and research personnel spend on research was hypothesised. Although the data was insufficient to confirm the non-spuriousness of the relationship, it was decided to go ahead with the relationship by using logical reasoning and the data trend at hand. This is a crucial assumption in the development of the HES model.

The Delphi study revealed that expert opinion found the following to be the foremost issues facing the HES R&D system in the next 20 years:

- poor prospects for retaining and rejuvenating the human resources stock
- poor prospect for adequate funding for R&D in the HES; and
- a deterioration of quality of human resources in the system.

The Delphi study was used to link the research questions asked in the study to likely scenarios in the following 20 years. These questions were specifically focussed on the effect of R&D investment on the system's ability to produce R&D. Some of the questions raised regarding the investment of R&D in the HES can be summarised as follows:

- how will the continuation of the current trends influence the system's performance in terms of R&D output created in the system?
- how will an increase/decrease of the current trends influence the system's performance in terms of R&D output created in the system?
- how could a policy of introducing dedicated researchers (research chairs) in the system influence the system's ability to produce R&D output?
- what could the delayed effect of postponing reacting on the system's degradation have on the system's ability to produce R&D output and to absorb knowledge in future?
- what implication could the improvement of academic and research staff's time management skills hold for the system?

The Delphi study's outcome was used to develop relevant scenarios to be tested on the model. These questions were tested in terms of scenario tests on the model. The results gained from the simulation model are presented in terms of a selection of scenario runs on the model. The following figure summarises the scenario tests ran on the model to provide possible answers to these questions.

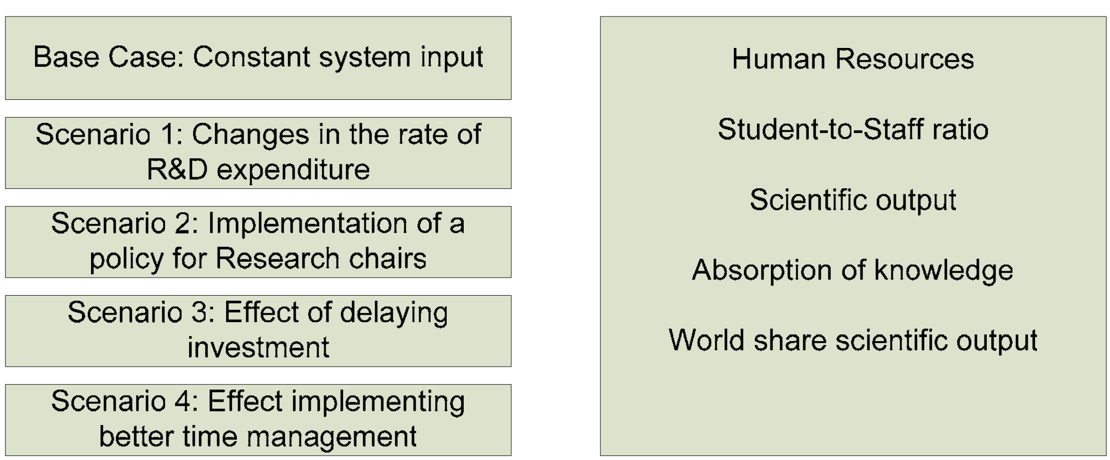



**Figure 10-3: Scenario Tests on the Higher Education Sector Model**

The conditions in the base case scenario were selected to tests for the policy condition of a constant 3% increase in both students as well as academic and research staff, resulting in a constant student-to-staff ratio. The base case scenario run revealed that although the system will continue to produce an increasing amount of papers per year, the experience level per academic and research staff (experience per headcount) will decrease from its current level.

The system model therefore yields the predicted output that a policy of maintaining the current student-to-staff ratio could result in academic and research staff loosing expertise, as the researchers in the system will be able to spend less time on R&D activities than in previous years. It can therefore be conclude that the base case scenario results in the decay of knowledge stocks and the levels of expertise of staff in the system, resulting in a lower publication rate per researcher in the system.

The effect of using an increase in the academic and research staff in the system as policy lever to reach a higher experience level per researcher in the system is tested in Scenario 1. The rate of HES expenditure, reflected in the academic and research staff employed on the system, was varied from 0% to 6%.

This test indicated that an increase in investment in the HES resulting in the growth of staff members to keep up with and exceed the growth of the student body, could have positive results. It is however also evident from model output that a considerable period of consistent increased investment will be necessary before the system will show an increase in the average level of tacit knowledge of human resources. It should also be kept in mind that such an increase in the experience level of academic and research personnel will only bear fruit after a considerable amount of time. Such an increase thus seems to be not only an extremely expensive solution but also a solution that will take too long to take affect to stop decay in expertise in the system.

A policy of creating experts in the system to preserve a certain level of expertise in personnel was also tested on the model. In Scenario 2, a policy to create centres of excellence through the implementation of research chairs was tested. The student-to-staff ratio kept constant at a specific level, after which the rest of the academic and research staff was allowed to spend all their time solely on research activities. The system dedicates researchers to be part-time research staff to maintain the student-to-staff ratio of 40 students per staff member. All extra appointments are dedicated research personnel. The output of the model revealed that the R&D output in the system could be increased considerably, should such a policy be followed. However, the applicability of such a policy will only be successful for increases in staff exceeding the increases in the student body.

The base case scenario as well as Scenario 1 clearly indicates that a reaction to the system decay is imperative. Scenario 3 aims to investigate the long term effect that disinvestment in R&D might have on the system. The experiment executed on the model comprised investigating the effect of a delayed reaction on the increasing student numbers and the resulting increasing student-to-staff ratio, resulting in a shrinking percentage of the time that academic and research staff spends on R&D activities. The decay of capacity and the inability to react on the system's decay will result in the system having a much lower scientific output rate. A conclusion can therefore be drawn that the model behaviour indicates that it will be more costly to rebuild lost capacity than to invest in the system to maintain its current levels.

Scenario 4 investigates the effect of the introduction of better time management skills to staff in the system. This is implemented altering the curve predicting the effect that the student-to-staff ratio might have on the time people spend on R&D. This policy also includes the improvement of time management skills due to different policies or through training. The output gained from the system model concludes that the policy of better time management in human resources in the HES could yield extremely very positive results for reversing the level of decay in the system. Although no data is available regarding the costs involved in introducing this policy, the costs for implementing such a policy is however likely to be much lower than the alternative of decreasing the student-to-staff ratio by hiring more people.

The policy recommendations that can be made to the Department of Education regarding R&D in the HES is thus that the HES should be protected against the effect of an increasing student body with no real increase in staff in the system.

Since a sudden increase of funding seems highly unlikely at this stage. The current situation can however be improved through a short-term solution of implementing a policy of improved time management in academic and research staff in the HES. It should however be kept in mind that the improvement of time management skills is only a temporary solution to the problem of an increasing student-to-staff ratio.

It is important for government to realise both the importance of an R&D capacity in the HES as well as the necessity of investing in it. The further decay of the already established capacity should not be allowed. As indicated in the scenario tests, a loss in capacity will be more expensive to rebuild than to maintain it at a current level. For this reason, the constant investment should be made in the development of young researchers to ensure the rejuvenation of the human resources stock and the future health of the HES R&D system.

### 10.2.3 Conclusions: public sector

#### 10.2.3.1 Model validation and criticisms

**Structure assessment test**

The level of aggregation is on the sector level, an accumulated level of all the R&D activities in organisations in the public sector. The analysis of the sector on an aggregate level includes different types of R&D output in the public sector. The system produces R&D output in the form of scientific papers and a small amount of patents:

- scientific publication data is used as an indicator for R&D output produced from basic, strategic and applied research performed in this sector; and

- patent data is used as a proxy for R&D outputs produced from developmental research performed in the public sector.

An attempt was made to include the different types of R&D and the different types of R&D output generated in the public sector.

Once again, it is stressed that the author is aware that the level of aggregation might be more revealing on a research field level or on an organisational level, i.e. government departments, science councils, museums etc.). As with the HES, the main reasons no attempt is made to analyse the system on a more detailed level are that the data is either unavailable or completely incompatible in terms of the level of aggregation and the classification of science fields with each other.

It is argued that there are certain advantages in the analysis of the system on a more aggregate level. The analysis and discussion is directed at a sector level rather than an organisational level or science field level. Simplicity is thus gained where accuracy is lost. By viewing the public sector as a whole, the system model becomes simpler and it is much easier to interpret the outcome of the simulation results into general policy recommendations. For this reason, the model is still useful to the purpose of the study, despite the lack of a more detailed analysis.

**Boundary adequacy**

The following model boundary chart was developed for the public sector model:

**Table 10-1: Model Boundary Chart of the Public Sector R&D System**

| Endogenous | Exogenous | Excluded |
|---|---|---|
| Absorptive capacity – rate of absorption of external knowledge through basic and applied R&D | Rate of world knowledge creation | Change in national priorities |
| Production function for R&D outputs - producing R&D outputs (patents and papers) | Researcher career span - average retirement age | Racial demographics of HR stock (can be included) |
| HR knowledge stock (experience stock) | Average knowledge life time - estimated from data | Absorptive capacity - rate of absorption of external knowledge through experimental development |
| Influence external knowledge has on absorptive capacity in basic and applied research | Salaries of R&D workers (used to compute the number of people employed for a specific spending) | Soft issues such as institutional culture, incentive programs for R&D output generation |
| Influence of HR and FTE on the system's ability to absorb knowledge | Growth rate of R&D workers' salary in the system. | Effect the private sector R&D activities have on the Public sector. |
| Influence of absorbed knowledge on system's ability to produce R&D output | Influence of school and university system on availability of R&D workers | Effect the HES R&D activities have on the public sector |

| | | |
|---|---|---|
| Influence of previous R&D experience and ability on absorptive capacity | Average percentage time spent by researcher staff on R&D activities | The effect the HES and the amount of students enrolled for S&T courses on the human resources stock |
| Employment of researchers (assume a steady supply stream of R&D personnel) | | Effect of geographical proximity |

A crucial assumption made in the application of the model is that the model is driven through funding. The model assumes a steady flow of trained human resources into the system and for the purpose of the simulation model, ignores the effect that restrictions on the availability of human resources might have on the inflow of research staff to the system. These issues are only taken into consideration when considering the effect of funding on the amount of human resources employed in the system.

The connection between the training of students to the availability of trained scientists and engineers on the system is also ignored. This again assumes a steady supply of human resources. The model output provides an indication of the human resources that will be employed in the system at a specific R&D expenditure rate.

**Model behaviour at extreme conditions and behaviour anomalies**

Extreme condition tests have been executed on the model. The following section provides a short description of the most important tests executed on the model:

*Test 1: The R&D expenditure drops to 0 in the year 2004*
*Expected reaction of system:* This should result in a zero headcount employed in the system, causing the knowledge stocks, i.e. experience stock, R&D knowledge stock and absorbed knowledge stock, to decay to a zero level.
*Outcome:* The system exhibits the expected behaviour.

*Test 2: The R&D effort by human resources drops to zero – 0% time spent on R&D by headcount*
*Expected reaction of system:* The percentage time spent on R&D drops to zero, no absorption or creation of knowledge takes place anymore. After a time, the experience stocks are also depleted.
*Outcome:* The system exhibits the expected behaviour.

*Test 3: World knowledge stock drops to 0*
*Expected reaction of system:* The rate at which the system absorbs knowledge starts decaying as the world knowledge stock starts decaying.
*Outcome:* The system exhibits the expected behaviour.

The modeller is satisfied that the model reacts to these tests in a satisfactory way.

**Parameter assessment**

The parameters chosen and tested for in the model is discussed in some detail in the data gathering and analysis chapter.

The parameters and constants chosen in the distribution of funding are calculated from the historical trends in the Frascati data. These trends revealed the percentage expenditure distribution to be constantly distributed on labour (43%), capital (7.7%) as well as running and other costs (49.3%).

The R&D outputs of basic (16%) and applied (55%) research performed in this sector are measured by the amount of scientific publications produced in the public sector. The parameter assessment in terms of the production functions for the development or creation of new knowledge and the absorption of knowledge was done by selecting two regression models:

- production function 1: development of knowledge (scientific publications); and
- production function 2: absorption of knowledge (citations from scientific publications).

R&D outputs from developmental research (29%) performed in this sector are measured by the amount of patents granted to organisations in the public sector. The parameter assessment in terms of the production functions for the development or creation of new knowledge and the absorption of knowledge was done by selecting a regression model:

- production function 3: development of knowledge (patents); and
- production function 4: the South African patent office does not examine the patents and there thus exists no account of the prior art used in the patents. In other words, there is no availability of data for the measurement of an absorption rate. This aspect therefore had to be ignored in this instance.

After trying various regression models, the model was selected on the basis of an acceptable coefficient of determination ($R^2$), which made sense in terms of the dynamics in the system and the significance of the parameters included in the regression model. All the variables included in the model proved to be highly significant and the selection was made for a level of 10%.

The models were tested rigorously for colinearity, heteroscedasticity and autoregression as well as spuriousness in the modelled relationship, i.e. stationarity. The tests proved that the models seem to be free of any of these problems.

Care must be taken with the interpretation of the results, as the time series data on which the regression was done spans only 20 years (20 data points), which could contribute to the over or underestimation of some of the parameters in the system. It is acknowledged that uncertainty exists regarding the estimated parameter values. For this reason, random variability is introduced to the model parameters in the model.

At this stage, we can conclude that with the data at hand and with what we have available, to us at this stage, the necessary tests were conducted successfully. We have thus decided to employ these relationships until such time as a re-estimation can be done on more data points.

**Behaviour reproduction test**

The foremost behaviour reproductions in the public sector model are discussed in this section.

The point-by-point fit of the model output of the rate at which the system produces new knowledge (R&D output) as well as the rate at which the system absorbs new knowledge is estimated in the SAS™ package. This is also presented in the sections where model parameters are estimated. The model output simulation runs and the model's ability to reproduce history are compared to model output in the simulation test runs.

*Production function 1: Development of knowledge (scientific publications)*

The output for the development of scientific output, measured in terms of scientific papers, yields a coefficient of the determination ($R^2$) of 0.46. The average of the model runs thus explains 46% of the variation in the actual data.

*Production function 2: Absorption of knowledge (citations from scientific publications)*

The output for the development of absorption of knowledge, measured in terms of references from South African authored scientific papers, yields a coefficient of determination ($R^2$) of 0.5317. The average of the model runs thus explains 53.17% of the variation in the actual data.

*Production function 3: Development of knowledge (patents)*

The output for the development of scientific output, measured in terms of patents granted at the South African patent office, yields a coefficient of the determination ($R^2$) of 0.50. The average of the model runs thus explains 50% of the variation in the actual data.

The section therefore holds that the recreation of the trend is less successful than in the HES. This however is the best fit that could be gained from the models tested. Through visual inspection was concluded that the model was successful in recreating main trends in the data. For this reason, the formulation was accepted to be included in the model.

The following section discusses the use of the development model to run various what-if scenario tests and policy tests.

**10.2.3.2 Summary of results**

A substantial amount of developmental research is performed within the public sector. The sector's R&D outputs are therefore not sufficiently represented when only considering scientific publications generated in the sector. The following proxies were chosen to measure the different types of research and the corresponding output in the public sector:

- the measure used for R&D outputs from basic, strategic and applied research performed in the sector is the amount of scientific publications produced in the public sector; and
- the measure used for R&D outputs from developmental research performed in the

sector is the amount of patents granted to organisations in the public sector.

The model is also developed with the 'Framework Autonomy and Base Line funding' policy in mind. This policy was implemented mainly to manage science councils. In terms of this policy, government fixed its subsidy to encourage councils to secure funding from clients in the public or private sectors. Although the policy was successful in increasing the linkages between councils and industry, there were a number of negative consequences on the culture of research within the councils. Research portfolios within councils became more market driven, while inevitably less attention was given to socio-economic and development goals. Collaboration between institutes declined and competition became the order of the day.

It was hypothesised that as the percentage contract research funding received by organisations in the public sector increases, the focus shifts from the creation of scientific output, such as scientific publications and patents.

The Delphi study revealed that expert opinion held the following to be the most pressing issues facing the public sector R&D system in the next 20 years:

- poor prospects for retaining and rejuvenating the human resources stock
- a deterioration of quality of human resources in the system; and
- poor prospect for adequate funding from government for R&D in the public sector.

These issues are closely interlinked with the research questions posed in this thesis. The Delphi study was used to link the research questions in the study to scenarios likely to exist in the following 20 years. The research question in the thesis is however focussed on the effect of R&D spending on the development of an R&D capacity in the system. The scenarios consequently focuses mainly on answering questions regarding the effect of R&D expenditure on the future R&D capacity of the R&D system.

Some of the questions raised regarding the investment of R&D in the public sector can be summarised as follows:

- how would the continuation of the current setting in the system (percentage contract funding and distribution of spending on the research types) influence the system's performance in terms of the R&D output created in the system?
- how would an increase/decrease of the current trends influence the system's performance in terms of the R&D output created in the system?
- how would changes in the total percentage of contract and state funding in the system influence the system's performance in terms of the R&D output created in the system?
- how would the combination of changes in the R&D expenditure and a shift away from the framework autonomy framework affect the system's performance in terms of the R&D output created in the system?

The Delphi study's outcome was used to develop relevant scenarios to be tested on the model. The following figure summarises the scenario tests ran on the model to provide possible answers to the questions posed in the study.

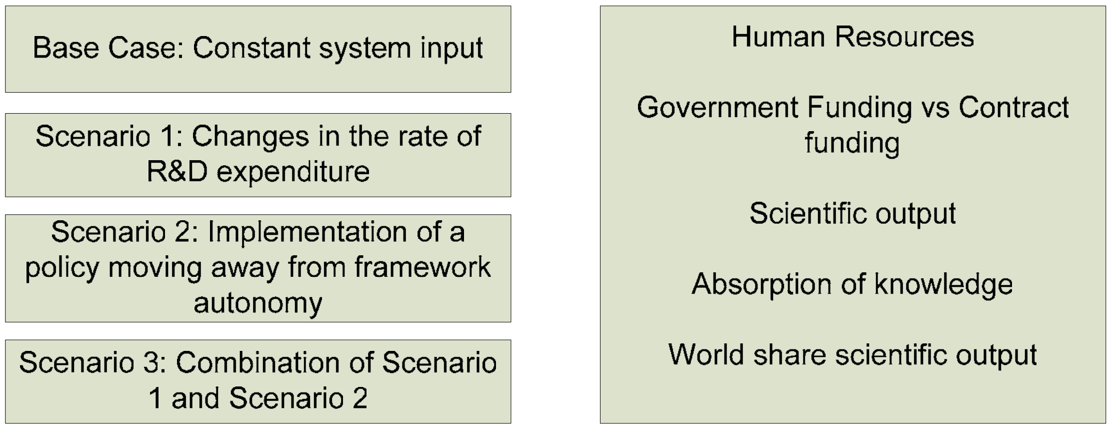



**Figure 10-4: Scenario Tests on the Public Sector Model**

The base case scenario holds that should the system be left unchanged in terms of the distribution of the funding as well as the R&D expenditure (in 2003 Rand), the knowledge creation output will remain relatively constant. The slight increase, which can also be seen in the rate at which the system is absorbing knowledge, can be attributed to knowledge spillovers from an external environment, which is continuing to produce an increasing amount of scientific output.

As the base case conditions yield a relatively constant output, the model behaviour under changing investment levels is investigated.

Scenario 1 tested the influence of increasing or decreasing the R&D expenditure in the public sector. Where an increasing number of research staff is employed in the system and as the knowledge stocks in the system increase, the knowledge creation output rate will increase. This behaviour is consistent with the understanding of the R&D system. An increased level of expenditure results in an increased stock of human resources, responsible for developing skills and tacit knowledge and thus creating an increased level R&D output in the system.

The changes in the framework autonomy policy currently in the system were also tested on the model. Scenario 2 assumes a constant total R&D expenditure in the system. A crucial assumption in the model was based on the hypothesis that an increased fraction of contract research funding results in a shift in focus from the creation of scientific output, such as scientific publications and patents. Different scenarios were run on the system to test for the possible effect that the shift in funding towards or away from contract funding might have on the system. The system's behaviour towards an increased level of contract funding is that of a decreasing trend of knowledge creation and absorption. This trend, in conjunction with human resources spending a greater portion of their time on contract research, also contributes to the resulting decreasing trend in terms of the generation of scientific output from the public sector.

Scenario 3 incorporates a combination of Scenarios 1 and 2. The model behaviour under changing conditions in the R&D expenditure in the system and a policy of either moving towards or away from framework autonomy is tested on the system model. The output gained from the model indicated that as the system moves away from framework autonomy, R&D outputs, i.e. scientific papers and patents, are likely to increase.

The simulated output results for the patent output generated in the public sector thus holds that the highest R&D output in terms of knowledge outputs in the system will be gained by increasing expenditure and decreasing the outsourcing of R&D capabilities. It must however be noted that the model's predicted output of the patents granted to the public sector remains low.

The policy of moving away from framework autonomy seems to yield positive results in terms of the production of knowledge output in the system. However, this must also be seen in the light that the system will in such instances be state-dependent. Should the system funding received from government be increased, the need for contract income will decrease, resulting in higher tangible R&D outputs. The trend is thus clear: if the sector wants to decrease funding from contract income, it will have to obtain increased government backing to be able to support the current level of R&D expenditure and to sustain the human resources base in the system.

Based on analysis of the model output gained from the scenario tests, policy recommendations to the public sector can thus be made. The shift away from framework autonomy could be successful in increasing R&D output obtained from the sector. This will however only be successful if government intends to contribute the portion of funding which will be lost from the income generated by contract research projects to the private sector. Should this not be done, the system will shrink and the increased levels of knowledge creation will not be reached.

### 10.2.4 Conclusions: private sector

#### 10.2.4.1 Model validation and criticisms

The tests as described in the methodology chapter were performed on the model. As the process of testing a model is iterative, the most recent results of these tests are reported in the following sections.

**Structure assessment test**

The level of aggregation is on the sector level, an accumulated level of all organisations in the private sector. As with the previous sectors, it must be admitted that the level of aggregation might be more revealing on a research field level or on an organisational level.

The main problem obstructing the analysis on a more detailed level is once again the availability of data. Obtaining reliable time series data for the years 1977 to 2003 proved extremely difficult. This was especially true for the availability of data and the nature of the aggregation of the data from different data sources. The main reasons for not analysing the system on a more detailed level are thus that the data was either unavailable or completely incompatible in terms of the level of aggregation and the classification of science fields with each other.

The measurement for R&D output in this sector is through the patents granted to South Africans at the USPTO.

**Boundary adequacy test**

The following model boundary chart was developed for the private sector model:

**Figure 10-5: Model Boundary Chart of the Private Sector Model**

| Endogenous | Exogenous | Excluded |
|---|---|---|
| Absorptive capacity - rate of absorption of external knowledge | Rate of world knowledge creation | Change in national priorities |
| Performance of R&D - productivity of producing R&D outputs | Researcher career span - average retirement age | Racial demographics of human resources stock |
| HR knowledge stock (experience stock) | Average knowledge life time - estimated from data | Effect of geographical proximity |
| Influence external knowledge has on absorptive capacity | Salaries of R&D workers (used to compute the number of people employed for a specific spending) | Effect of HES on the availability of human resources for R&D |
| Influence of human resources and FTE on the system's ability to absorb knowledge | Growth rate of R&D workers' salary in the system | Effect of public sector R&D activities |
| Influence of absorbed knowledge on system | Percentage time spent by the average researcher on R&D activities | The effect the HES and the amount of students enrolled for S&T courses on the HR stock |
| Influence of previous R&D experience and ability to produce output on absorptive capacity | | Soft issues such as institutional culture, incentive programmes for R&D output generation |
| Employment of researchers (assume a steady supply stream of R&D personnel) | | Effect the HES R&D activities have on the private sector |
| Effect of fiscal incentives | | Effect the public sector R&D activities have on the private sector |

**Parameter assessment test**

The parameters and constants chosen in the distribution of funding are calculated from the historical trends in the Frascati data. These trends hold that the percentage expenditure distribution is constantly distributed on labour (50%), capital (11%) as well as running and other costs (39%).

The proxy chosen to measure R&D output gained from basic (6%), applied (35%) and experimental development (59%) research performed in this sector is patents granted at the USPTO. The parameter assessment in terms of the production functions for the development or creation of new knowledge and the absorption of knowledge was done by selecting two regression models:

- production function 1: development of knowledge (patents); and
- production function 2: absorption of knowledge (prior art cited in patents)

After trying various regression models, a model was finally selected on the basis of making sense in terms of the dynamics in the system, an acceptable coefficient of determination ($R^2$) and the significance of the parameters included in the regression model. All the variables included in the model proved highly significant and the selection was made for a level of 5%.

Care must be taken with the interpretation of the results, as the time series data on which the regression was done spanned only 20 years (20 data points), which could contribute to the over or underestimation of some of the relationships. At this stage it was however concluded that the necessary tests were conducted successfully with the data at hand and with what was available at that stage.

The models were tested rigorously for colinearity, heteroscedasticity and autoregression and spuriousness in the modelled relationship, i.e. stationarity. The tests proved that the models seemed free of any of the above problems. It was therefore decided to employ these relationships until such time as more data points or a more appropriate model became available.

The model output revealed that the model exhibited a numerical sensitivity to variability in the parameters in the system. Model sensitivity in terms of the output of patents registered at the USPTO created in the system through the variability in the parameters in the production functions was also observed.

**Extreme conditions test**

Extreme condition tests have been executed on the model. The following is a short description of the most important tests executed on the model:

*Test 1: The R&D expenditure drops to 0 in the year 2004*
*Expected reaction of system:* This should result in a zero headcount employed in the system, causing knowledge stocks, i.e. experience stock, R&D knowledge stock and absorbed knowledge stock, to become depleted after a period of constant decay.
*Outcome:* The system exhibits the expected behaviour.

*Test 2: No FTE in system*
*Expected reaction of system:* The percentage time spent on R&D drops to zero, no absorption or creation of knowledge takes place anymore.
*Outcome:* The system exhibits the expected behaviour.

*Test 3: World knowledge stock drops to 0*
*Expected reaction of system:* The rate at which the system is absorbing knowledge starts decaying as the world knowledge stock starts decaying.
*Outcome:* The system exhibits the expected behaviour.

The modeller is satisfied that the model reacts to all these tests in a satisfactory way.

**Behaviour reproduction test**
The most important behaviour reproductions in the private sector model are discussed in this section.

The point-by-point fit of the model for the rate at which the system produces new knowledge (scientific output) as well as the rate at which the system absorbs new knowledge is estimated in the SAS™ package. This is also presented in the sections where model parameters are estimated. The model output simulation runs and the model's ability to reproduce history are compared to model output in the simulation test runs.

Since patents are used as a measure of the development of new knowledge in the sector, the absorption of knowledge is also measured through the rate at which scientists read, interpret and use knowledge created in the external environment to produce new knowledge. The prior art cited in the patents granted to South Africans at the USPTO is used as a measure of the absorption of knowledge.

*Production function 1: Development of knowledge (patents)*
The output for the development of scientific output, measured in terms of patents, yields a coefficient of determination ($R^2$) of 0.600349. The average of the model runs thus explains 60% of the variation in the actual data.

*Production function 2: Absorption of knowledge (patent citation count)*
The output for the development of absorption of knowledge, measured in terms of citations made to prior art in SA patents, yields a coefficient of the determination ($R^2$) of 0.6409. The average of the model runs thus explains 64% of the variation in the actual data.

The conclusion reached from behaviour reproduction tests is that a satisfactory coefficient of determination was achieved for both trends recreated.

### 10.2.4.2 Summary of results
The Delphi study revealed that expert opinion believed the following to be the most pressing issues facing the private sector R&D system in the next 20 years:

- a lack of a research culture poses a hurdle for the development of an R&D capacity
- a deterioration of quality of human resources in the system; and
- poor prospects for retaining and rejuvenating the human resources stock.

These issues are also closely interlinked with the research questions posed in this thesis. The research question in the thesis is however focussed on the effect of R&D spending on the development of an R&D capacity in the system. Consequently, the scenarios focus mainly on answering the following questions regarding the effect of R&D expenditure on the future R&D capacity of the R&D system.

- How would a constant investment in the South African private sector affect its ability to produce R&D output and absorb knowledge?
- How would an increasing/decreasing level of investment in the South African private sector affect its ability to produce R&D output and absorb knowledge?
- How would the introduction of fiscal incentives influence R&D expenditure and the ability to produce R&D output and absorb knowledge?

The Delphi study's outcome was used to develop relevant scenarios to be tested on the model. The following figure summarises the scenario tests ran on the model to provide possible answers to the questions posed in the study.

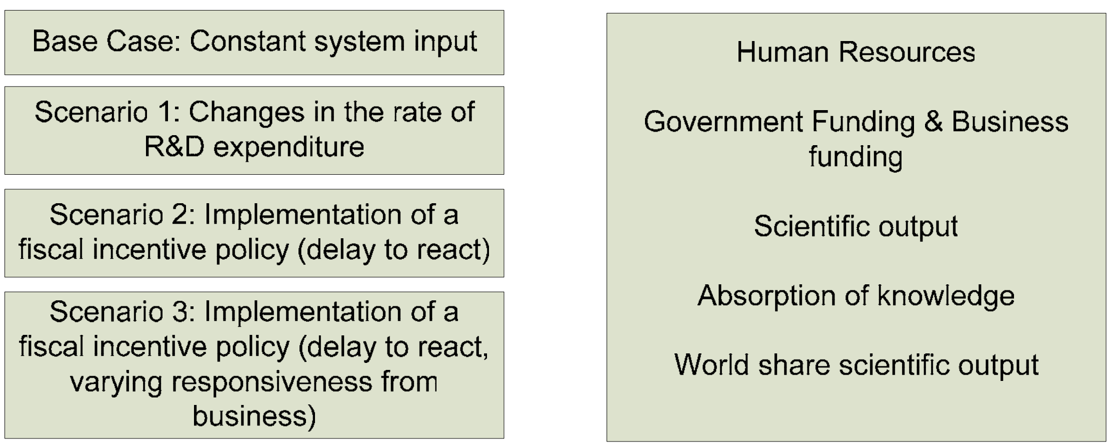



**Figure 10-6: Scenario Tests on the Private Sector Model**

The base case simulation runs executed on the model firstly aims to test the predicted trend in the private sector for a scenario where conditions remain constant with the situation in 2003. The base case scenario thus holds that should the system be left unchanged in terms of the distribution of the funding as well as the R&D expenditure (in 2003 Rand), the model predicts a small but gradual increase in the number of patents granted. This continued increase is attributed to the continued increase in knowledge in the external environment, resulting in a knowledge spillover and transfer into the R&D system.

Scenario 1 aims to test model output and predicted system performance under different changes in business R&D expenditure. Policy conclusions can be drawn from the output gained. An increase in R&D expenditure in the system results in an increasing number of research staff employed and as the knowledge stocks in the system are being built up, the system's ability to produce R&D output will increase. An increase in R&D expenditure implies an increase in the human resources stock in the system. The increase in R&D expenditure will have a positive influence on output as well as the development of researchers only if trained people can be found to be employed in the system.

A policy suggested by many for boosting private sector R&D is tested. Scenario 2 thus proposes to explore possible system behaviour by testing the outcome of applying fiscal incentives on the system model. In the scenario, simulations are run for different reaction times for industry to respond to tax incentives. The policy conclusion that can be drawn from this scenario is that a slower rate to reach an elasticity of unity does not influence the eventual success of the tax incentive scheme, but only the time to reach it. It can therefore be concluded that the time period for which the incentive scheme will be implemented could be an important determining factor of such a scheme's success.

Scenario 3 thus aims to examine and compare the model's predicted output for different levels of responsiveness from the private sector to tax incentive schemes in conjunction with varying delays of the private sector to react to these incentives:

- axis 1: change in the private sector responsiveness to tax incentives (0.4 to 1.6); and
- axis 2: change in the scenario runs are executed for different responsiveness time delays of 5 to 15 years.

The output of the model thus concludes that business R&D expenditure could be increased by implementing a policy of fiscal incentives. The success of the scheme would be influenced by business firms' ability to react on the fiscal incentives scheme within a reasonable amount of time and a high as possible level of responsiveness (elasticity). It is however also evident that the success of such a scheme would depend on the continuity of its implementation.

Policy recommendations can therefore be made stating that to boost R&D expenditure in the private sector, a policy of fiscal incentives should be implemented. Based on research by Pouris (2003), this study also confirms that the implementation of fiscal incentives in the SA private sector could significantly increase R&D expenditure. This will result in a system that will be better positioned to compete with other countries, since R&D incentives will make South Africa a more attractive location for multinational enterprises to base their R&D activities.

### 10.3 Implications for Contributions to Theory and Practice

Although system dynamics has been used to formulate strategy within the South African S&T system, no model of R&D output as a function of long-term effects of investment in R&D was available for South Africa. The development of this model is a step towards the development of a model using Frascati R&D survey input data.

The model developed in this thesis resulted in a better understanding of the R&D subsystem from a NSI perspective. A dynamic description of the interactions and causal relationships between elements in the system, incorporating the dynamics of the learning process of R&D, was formulated.

A conceptual system dynamics model was developed for an R&D performing sector in an NSI. This sector model was applied to three South African sectors, namely the HES as well as the public and private sector. The aim of implementing the theoretically developed model to the sectors is to validate the model. By applying the model to these sectors, a policy tool was developed for the use of decision-makers in government and industry. The model will be offered to the National Advisory Council on Innovation for possible use to analyse policy alternatives regarding R&D strategies for the government.

### 10.3.1 SD model of the creation and absorption of knowledge

The dynamic model was developed from the NSI perspective, drawing on the work of Romer (1990), Lundvall (1992) and Rosenberg (2000), as the model acknowledges the central role of knowledge and the availability of human resources (Romer (1990), Porter (1990), Lundvall (1992) and Johnson (1992), Niosi (2002), Nasierowski and Arcelus (1999)) as inputs to system performance.

The implementation of the dynamic model of the creation of knowledge employs two major feedback loops, namely the creation of knowledge and the absorption of knowledge. Through this structure and by introducing learning curves (Sterman, 2000), the model also attempted to include the effects of 'learning by doing' (Arrow, 1962), 'learning by using' (Rosenberg) and 'learning by interacting (Lundvall, 1992b).

The contribution to theory was the development of a systems dynamics account of the creation of R&D (knowledge) in an R&D performing sector.

### 10.3.2 Analysis of R&D indicators and data

The thesis included a data gathering phase in which the analysis of data regarding the South African R&D system took place:

- gathered statistics on R&D output and policy analysis from government documents and policy reports
- gathered HEMIS database data for the period 1985 to 2004 for figures on student and staff numbers in the South African HES
- gathered R&D data from Frascati surveys for the years 1977 to 2003. Analysed and categorised data
- developed a database with all ISI scientific journal publications by South Africans from 1980 to 2003. Analysis of the publication trends and the contributions made by the three R&D sectors analysed in the thesis
- analysed of all patents granted to South Africans at the South African patent office. Scrutinised all South African patent journals for the period 1985 to2005
- analysed the NBER database and extracted information on patents granted to South Africans at the USPTO; and
- Delphi study. A panel of experts were used to gather data on likely future issues in South Africa's R&D system as well as on the appropriateness of indicators used for

measuring R&D output in the HES, public and private sectors.

### 10.3.3 Contribution to the system dynamics body of knowledge

This research project employs the system dynamic methodology's ability to model complex dynamic systems. The research will contribute to the system dynamics body of knowledge by illustrating the use of system dynamics methodology and computer simulation for the planning and management of R&D investment within the South African R&D system.

### 10.3.4 Practical implications and policy recommendations

The practical implication of the study is best explained by explicitly referring back to the original practical research question posed in Chapter 1:

*"What is the effect of R&D input an the ability of the system to create R&D output and to assimilate knowledge"*

The overall finding was that a sustained investment in R&D is very important for the future of South Africa's R&D capacity in the future. Where evidence of the decay on R&D investment was found, evidence of a decay of the ability of the system to create R&D output was also evident.

The answer to the research question was treated for the separate sections in this chapter. In summary the following answers can be given in response to the research question posed in Chapter 1.

**The Higher Education Sector**

The following research question was posed in Chapter 1:

*"What is the effect of R&D input an the ability of the HES to create R&D output and to assimilate knowledge"*

The following answers to this question were obtained from the simulation runs on the model:

- **The effect of maintaining a constant level of R&D input:** Maintaining the current student-to-staff ratio (translating in a constant R&D inputs) could result in academic and research staff loosing expertise. It can therefore be concluded that this could lead to the decay of knowledge stocks and the levels of expertise of staff in the system, resulting in a lower publication rate per researcher in the system.
- **The effect of increasing R&D input:** It was found that an increase in investment in the HES resulting in the growth of staff members to keep up with and exceed the growth of the student body, could have positive results. It is however also evident from model output that a considerable period of consistent increased

investment will be necessary before the system will show an increase in the average level of tacit knowledge of human resources.
- **The effect of decreasing R&D input in the HES:** The study investigated the long term effect that disinvestment in R&D might have on the system. The decay of capacity and the inability to react on the system's decay will result in the system having a much lower scientific output rate. A conclusion can therefore be drawn that the model behaviour indicates that it will be more costly to rebuild lost capacity than to invest in the system to maintain its current levels.

Policy tests were conducted on the model which could have some practical implications for practice.

- The effect of implementing a policy to create centres of excellence through the implementation of research chairs was tested. The output of the model revealed that the R&D output in the system could be increased considerably, should such a policy be followed. However, the applicability of such a policy will only be successful for increases in staff exceeding the increases in the student body.
- A policy of better time management in human resources in the HES could yield very positive results for reversing the level of decay in the system. Although no data is available regarding the costs involved in introducing this policy, the costs for implementing such a policy is however likely to be much lower than the alternative of decreasing the student-to-staff ratio by hiring more people.

Policy recommendations can be made to the Department of Education regarding R&D in the Higher Education System.

Firstly, the HES should be protected against the effect of increasing number of the student body with no real increase in staff in the system. A sudden increase of funding seems highly unlikely at this stage. The current situation can however be improved through a short-term solution of implementing a policy of improved time management in academic and research staff in the HES. It should however be kept in mind that the improvement of time management skills is only a temporary solution to the problem of an increasing student-to-staff ratio.

It is important for government to realise both the importance of an R&D capacity in the HES as well as the necessity of investing in it. The further decay of the already established capacity should not be allowed. As indicated in the scenario tests, a loss in capacity will be more expensive to rebuild than to maintain it at a current level. For this reason, the constant investment should be made in the development of young researchers to ensure the rejuvenation of the human resources stock and the future health of the HES R&D system.

**Public sector**

The following research question was posed in Chapter 1:

*"What is the effect of R&D input an the ability of HES to create R&D output and to*

*assimilate knowledge"*

The following answers to this question were obtained from the simulation runs on the model:

- **The effect of maintaining R&D input in the Public sector:** Should the system be left unchanged in terms of the distribution of the funding as well as the R&D expenditure (in 2003 Rand), the knowledge creation output will remain relatively constant. The slight increase, which can also be seen in the rate at which the system is absorbing knowledge, can be attributed to knowledge spillovers from an external environment, which is continuing to produce an increasing amount of scientific output.
- **The effect of increasing R&D input:** Where an increasing number of research staff is employed in the system and as the knowledge stocks in the system increase, the knowledge creation output rate will increase. This behaviour is consistent with the understanding of the R&D system. An increased level of expenditure results in an increased stock of human resources, responsible for developing skills and tacit knowledge and thus creating an increased level R&D output in the system.
- **The effect of decreasing R&D input:** Decreasing the number of research staff in the system leads to a decrease of knowledge stocks in the system resulting in lower R&D output generation.

Policy tests were conducted on the model which could have some practical implications for practice.

- The changes in the framework autonomy policy currently in the system were also tested on the model. Different scenarios were run on the system to test for the possible effect that the shift in funding towards or away from contract funding might have on the system. The system's behaviour towards an increased level of contract funding is that of a decreasing trend of knowledge creation and absorption. This trend, in conjunction with human resources spending a greater portion of their time on contract research, also contributes to the resulting decreasing trend in terms of the generation of scientific output from the public sector.
- The model behaviour under changing conditions in the R&D expenditure in the system and a policy of either moving towards or away from framework autonomy is tested on the system model. The output gained from the model indicated that as the system moves away from framework autonomy, R&D outputs, i.e. scientific papers and patents, are likely to increase.

*The simulated output results for the patent output generated in the public sector thus holds that the highest R&D output in terms of knowledge outputs in the system will be gained by increasing expenditure and decreasing the outsourcing of R&D capabilities.*

Based on analysis of the model output gained from the scenario tests, policy recommendations to the public sector can thus be made. The shift away from framework autonomy could be successful in increasing R&D output obtained from the sector. This will however only be successful if government intends to contribute the portion of funding which will be lost from the income generated by contract research projects to the private sector. Should this not be done, the system will shrink and the increased levels of knowledge creation will not be reached.

**Private sector**

The following research question was posed in Chapter 1:

*"What is the effect of R&D input an the ability of the Private sector to create R&D output and to assimilate knowledge"*

The following answers to this question were obtained from the simulation runs on the model:

- **The effect of maintaining current levels R&D input in the Private sector:** Should current levels of R&D input be left unchanged in terms of the distribution of the funding as well as the R&D expenditure (in 2003 Rand), the model predicts a small but gradual increase in the number of patents granted. This continued increase is attributed to the continued increase in knowledge in the external environment, resulting in a knowledge spillover and transfer into the R&D system.
- **The effect of increasing R&D input in the Private Sector:** An increase in R&D input in the system results in an increasing number of research staff employed and as the knowledge stocks in the system are being built up, the system's ability to produce R&D output will increase.

A policy suggested by many for boosting private sector R&D was tested on the model. A policy conclusion can be drawn from this scenario – a slower rate to reach an elasticity of unity does not influence the eventual success of the tax incentive scheme, but only the time to reach it. It can therefore be concluded that the time period for which the incentive scheme will be implemented could be an important determining factor of such a scheme's success.

Policy recommendations can therefore be made stating that to boost R&D expenditure in the private sector; a policy of fiscal incentives should be implemented. Based on research by Pouris (2003), this study also confirms that the implementation of fiscal incentives in the SA private sector could significantly increase R&D expenditure. This will result in a system that will be better positioned to compete with other countries, since R&D incentives could also make South Africa a more attractive location for multinational enterprises to base their R&D activities.

### 10.3.5 Overall shortcomings of study

Data was gathered from the R&D Surveys for the years 1981-2003. Some shortcomings exist in the continuity of the time series data used for this study. Some gaps in the time series data exist for the years 1995 and 1999. Where data was found missing for certain years (1995, 1999), data was extrapolated in order to correct for this issue.

Different survey methodologies for the R&D survey over some years. This issue mostly exists for the Higher Education Sector. It was corrected for as far as possible by using the HEMIS data for the Human Resources count data in this sector. It was found that the methodological changes did not exist for the survey for the Public and Private sector.

It is also important to keep in mind that the indicators used for the quantification R&D output are imperfect proxies of the level of R&D output produced in a sector. Although using patent and scientific paper output as measures of R&D output is a widely acknowledged and used measure, the relevance of using it in South Africa (with a developing economy and R&D system) had to be tested. A Delphi study was conducted to ensure that the indicators used would be a sound mechanism of measuring R&D output in the different sectors modelled in the study. As no better source of data or of measuring R&D input or output could be obtained; the existing measures had to be used.

Care must be taken with the interpretation of the results, as the time series data on which the regression was done spans only 20 years (20 data points), which could contribute to the over or underestimation of some of the parameters in the system. It is acknowledged that uncertainty exists regarding the estimated parameter values. In order to compensate for this shortcoming, random variability is introduced to the model parameters in the model.

A common problem in modelling social systems is the level of uncertainty as well as the difficulty of finding ways to quantify soft variables included in these systems. This model is no exception. The model fails to include the effect that soft issues might have on the percentage time that staff in the system will spend on R&D activities. Examples of these disregarded variables include institutional culture, changes in people's attitude towards R&D and policies implemented to urge R&D output, such as including R&D output by staff as a measure in their annual performance review. This list can be expanded. It is however impossible to obtain measures for these values over a 20 year period. This is just one of the difficulties experienced when modelling a social system.

Conclusions that can be drawn from this section are that although this study does suffer from shortcomings, as much as possible was done to identify these issues and where possible all in the author's power was done to compensate for it or where no correction was possible, the limitations were clearly stated.

## 10.4 Future Work

The model developed in this thesis employs Frascati R&D survey data as well as patent and scientific publication output data. These are all standard R&D input and output indicators. It should therefore be relatively simple to apply the model to any other sector for which data is gathered in this format. This also opens up the possibility of applying the model to other countries. Where better continuity existed in the methodology followed, more developed countries could facilitate a more complete set of time series data from R&D surveys. In this instance, the possibility arises that the model could be applied on a more detailed level of aggregation, such as a scientific field level.

At this stage, the model does not include the effect the different sectors might have on each other; future work can also incorporate the effect of the different R&D sectors on each other. This could include incorporating a framework, such as the triple helix, in the model.

Future work can also include expanding the model from being merely expenditure driven to including demand functions for R&D expenditure, incorporating a feedback loop from the R&D activities in the system.

At this stage, the model assumes a steady supply of trained human resources into the human resources stock. Future work can incorporate the effect that the training of skilled human resources in the South African HES as well as the secondary education system might have on the supply of trained human resources to the R&D system.

Future work can also include the model's R&D output being linked to an econometric model of the GDP growth of a country. The improved model could incorporate a feedback to R&D expenditure as a percentage of GDP.

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# 12 APPENDIX A

## 12.1 South Africa's Patenting at the USPTO

The database used for data analysis on the patenting statistics of South Africa at the United States Patent Office was obtained from the National Bureau of Economic Research (NBER) in Cambridge, Massachusetts in the Unite States of America. This is available for free download at the following location: http://www.nber.org/patents/

The main data set extends from January 1, 1963 through December 30, 1999 (37 years), and includes (Hall et al, 2001):

- All the ***utility*** patents granted during that period, totalling 2,923,922 patents
- The citations file, includes all citations made by patents granted in 1975-1999, totalling 16,522,438 citations.
- Data on inventors and assignees.

The following table includes fields in the database, which are relevant to the information extracted in this study. For a more detailed account of what is included in the database, see NBER (2001).

**Table 12-1: Field included in the database relevant to the analysis for this study**

| Field Name | Field Used |
|---|---|
| Patent number | |
| Grant year | |
| Grant date6 | |
| Application year (starting in 1967) | Used |
| Country of first inventor | Used |
| State of first inventor (if U. S.) | |
| Assignee identifier, if the patent was assigned (starting in 1969) | |
| Assignee type (i.e., individual, corporate, or government; foreign or domestic) | Used |
| Technological category | |
| Technological sub-category | |
| Number of citations made | Used |
| Number of citations received | Used |
| Percent of citations made by this patent to patents granted since 19637 | |
| Measure of "generality" | |

Each patent document includes the date when the inventor filed for the patent (the ***application*** date), and the date when the patent was granted. The data contains the grant ***date*** and the grant ***year*** of all patents in the file (i.e., of all utility patents granted since 1963) and the application ***year*** for patents granted since 1967. The grant date depends upon the review process at the Patent Office, which takes on average about 2 years with a significant variance (NBER, 2001).

For the analysis, the actual timing of the patented inventions is closer to the application date than to the (subsequent) grant date. This is so because inventors have a strong incentive to apply for a patent as soon as possible following the completion of the innovation.

The following table lists the Patents filed where the first inventor was a South African. For the purpose of this discussion, from this point forward this subset of data within the database is referred to as “SA Patents” .The “References” column lists the summation of all the citations made from the patent to prior art.

**Table 12-2: South African Patent outputs at the USPTO**

| Application Year | World patent output | SA patents registered at USPTO | References |
|---|---|---|---|
| 1980 | | | |
| 1981 | 63910 | 71 | 426 |
| 1982 | 65009 | 78 | 502 |
| 1983 | 61563 | 74 | 424 |
| 1984 | 67071 | 90 | 504 |
| 1985 | 71442 | 89 | 622 |
| 1986 | 75088 | 89 | 692 |
| 1987 | 81458 | 130 | 908 |
| 1988 | 90134 | 95 | 654 |
| 1989 | 96077 | 124 | 839 |
| 1990 | 99254 | 98 | 733 |
| 1991 | 100016 | 88 | 619 |
| 1992 | 103307 | 96 | 765 |
| 1993 | 106848 | 143 | 1272 |
| 1994 | 120380 | 138 | 1204 |
| 1995 | 137661 | 98 | 922 |
| 1996 | 131450 | 107 | 928 |
| 1997 | 114881 | 81 | 739 |
| 1998 | 33780 | 25 | 217 |
| 1999 | 1560 | 2 | 25 |
| 2000 | - | - | - |
| 2001 | - | - | - |

Hall et al (NBER ,2001) warns against ***truncation*** problem: as the time series move closer to the last date in the data set, patent data timed according to the application date will increasingly suffer from missing observations consisting of patents filed in recent years that have not yet been granted. This issue is dealt with by only making use of the time series up to 1996.

***Type of assignees***

The USPTO classifies patents according to the type of assignees (owners of the patent rights), into the following seven categories (the figures are the percentages of each of these categories in our data):

**Table 12-3: USPTO Assignee type categories**

| Assignee # | Assignee type |
|---|---|
| 1 | Unassigned |
| 2 | US non-government organization (mostly corporations) |
| 3 | Non-US non-government organization (mostly corporations) |
| 4 | US individuals |
| 5 | Non-US individuals |
| 6 | US Federal Government |
| 7 | Non US Government |

“Unassigned” patents are those for which the inventors have not yet granted the rights to the invention to a legal entity such as a corporation, university or government agency, or to other individuals. The original inventors thus still owned these patents at the time of patenting, and they may or may have not transferred their patent rights at a later time (the NBER do not have data on transfers done after the grant date).

The SA Patent dataset was now further analysed, the analysis yields the following distribution of patents to the assignee types. The year is the application year – the date earliest to the actual invention date.

**Table 12-4: South African Patent counts at the USPTO**

| | Category number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **Total** |
| **1977** | 43 | 1 | 26 | 0 | 4 | 0 | 0 | 74 |
| **1978** | 39 | 4 | 40 | 0 | 4 | 0 | 0 | 87 |
| **1979** | 42 | 2 | 44 | 0 | 6 | 0 | 0 | 94 |
| **1980** | 35 | 6 | 42 | 0 | 3 | 0 | 0 | 86 |
| **1981** | 28 | 1 | 37 | 0 | 4 | 0 | 1 | 71 |
| **1982** | 25 | 2 | 49 | 0 | 1 | 0 | 1 | 78 |
| **1983** | 28 | 3 | 42 | 0 | 1 | 0 | 0 | 74 |
| **1984** | 38 | 1 | 46 | 0 | 5 | 0 | 0 | 90 |
| **1985** | 28 | 3 | 56 | 0 | 2 | 0 | 0 | 89 |
| **1986** | 34 | 1 | 47 | 0 | 7 | 0 | 0 | 89 |
| **1987** | 66 | 2 | 57 | 0 | 4 | 0 | 1 | 130 |
| **1988** | 43 | 2 | 46 | 1 | 3 | 0 | 0 | 95 |
| **1989** | 48 | 4 | 65 | 0 | 5 | 0 | 2 | 124 |
| **1990** | 38 | 5 | 50 | 0 | 3 | 0 | 2 | 98 |
| **1991** | 38 | 3 | 44 | 0 | 2 | 0 | 1 | 88 |
| **1992** | 36 | 5 | 53 | 0 | 2 | 0 | 0 | 96 |
| **1993** | 62 | 3 | 74 | 0 | 4 | 0 | 0 | 143 |
| **1994** | 53 | 8 | 74 | 0 | 3 | 0 | 0 | 138 |
| **1995** | 39 | 5 | 47 | 0 | 7 | 0 | 0 | 98 |
| **1996** | 32 | 5 | 61 | 1 | 8 | 0 | 0 | 107 |
| **1997** | 29 | 11 | 62 | 0 | 1 | 0 | 0 | 103 |
| **1998** | 31 | 11 | 64 | 0 | 3 | 0 | 0 | 109 |
| **1999** | 30 | 4 | 73 | 1 | 5 | 0 | 0 | 113 |

It can be noticed from the above table that the two groups with the most patents are the “unassigned” group as well as the “Non-US non-government organization (mostly corporations)” group.

Certain assumptions are made regarding the assignee classifications and the implications on categorising it to the three sectors in the model developed in this study (Higher Education sector, Public sector and Private sector)

- All patents in category 2 and 3 are patents originating from companies in the “Private sector”
- An assumption is made that the unassigned entities will never be assigned and will remain in the names of the inventors who originally submitted the application for patents.

These assignee codes are then assigned to one of three categories.
- No Sector: Unassigned (1) and Individuals (4,5)
- Private sector: Non governmental organisations (2, 3)
- Governmental organisations (7) – Public sector

This yields the following result:

**Table 12-5: Patent count analysis of South African Patents at the USPTO**

| Patents | No sector | Private sector | Public sector | Total |
|---|---|---|---|---|
| 1977 | 47 | 27 | 0 | 74 |
| 1978 | 43 | 44 | 0 | 87 |
| 1979 | 48 | 46 | 0 | 94 |
| 1980 | 38 | 48 | 0 | 86 |
| 1981 | 32 | 38 | 1 | 71 |
| 1982 | 26 | 51 | 1 | 78 |
| 1983 | 29 | 45 | 0 | 74 |
| 1984 | 43 | 47 | 0 | 90 |
| 1985 | 30 | 59 | 0 | 89 |
| 1986 | 41 | 48 | 0 | 89 |
| 1987 | 70 | 59 | 1 | 130 |
| 1988 | 47 | 48 | 0 | 95 |
| 1989 | 53 | 69 | 2 | 124 |
| 1990 | 41 | 55 | 2 | 98 |
| 1991 | 40 | 47 | 1 | 88 |
| 1992 | 38 | 58 | 0 | 96 |
| 1993 | 66 | 77 | 0 | 143 |
| 1994 | 56 | 82 | 0 | 138 |
| 1995 | 46 | 52 | 0 | 98 |
| 1996 | 41 | 66 | 0 | 107 |
| 1997 | 30 | 73 | 0 | 103 |
| 1998 | 34 | 75 | 0 | 109 |
| 1999 | 36 | 77 | 0 | 113 |

### 12.1.1 Absorption of knowledge from the USPTO database

**Table 12-6: South African Patent reference counts at the USPTO**

| | Category number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total |
| **1977** | 256 | 30 | 144 | 0 | 18 | 0 | 0 | 448 |
| **1978** | 272 | 30 | 243 | 0 | 26 | 0 | 0 | 571 |
| **1979** | 302 | 12 | 294 | 0 | 45 | 0 | 0 | 653 |
| **1980** | 226 | 30 | 233 | 0 | 13 | 0 | 0 | 502 |
| **1981** | 201 | 5 | 178 | 0 | 31 | 0 | 11 | 426 |
| **1982** | 180 | 15 | 299 | 0 | 5 | 0 | 3 | 502 |
| **1983** | 172 | 22 | 223 | 0 | 7 | 0 | 0 | 424 |
| **1984** | 225 | 10 | 240 | 0 | 29 | 0 | 0 | 504 |
| **1985** | 199 | 39 | 368 | 0 | 16 | 0 | 0 | 622 |
| **1986** | 279 | 3 | 377 | 0 | 33 | 0 | 0 | 692 |
| **1987** | 494 | 21 | 358 | 0 | 32 | 0 | 3 | 908 |
| **1988** | 284 | 11 | 333 | 11 | 15 | 0 | 0 | 654 |
| **1989** | 331 | 37 | 451 | 0 | 19 | 0 | 1 | 839 |
| **1990** | 265 | 49 | 388 | 0 | 18 | 0 | 13 | 733 |
| **1991** | 284 | 4 | 312 | 0 | 19 | 0 | 0 | 619 |
| **1992** | 324 | 42 | 388 | 0 | 11 | 0 | 0 | 765 |
| **1993** | 546 | 24 | 632 | 0 | 70 | 0 | 0 | 1272 |
| **1994** | 446 | 165 | 575 | 0 | 18 | 0 | 0 | 1204 |
| **1995** | 351 | 79 | 418 | 0 | 74 | 0 | 0 | 922 |
| **1996** | 336 | 44 | 469 | 4 | 75 | 0 | 0 | 928 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **1997** | 159 | 120 | 460 | 0 | 0 | 0 | 0 | 739 |
| **1998** | 45 | 15 | 157 | 0 | 0 | 0 | 0 | 217 |

**Table 12-7: Patent reference count analysis of South African Patents at the USPTO**

| Patents | No sector | Private sector | Public sector | Total |
|---|---|---|---|---|
| 1977 | 274 | 174 | 0 | 448 |
| 1978 | 298 | 273 | 0 | 571 |
| 1979 | 347 | 306 | 0 | 653 |
| 1980 | 239 | 263 | 0 | 502 |
| 1981 | 232 | 183 | 11 | 426 |
| 1982 | 185 | 314 | 3 | 502 |
| 1983 | 179 | 245 | 0 | 424 |
| 1984 | 254 | 250 | 0 | 504 |
| 1985 | 215 | 407 | 0 | 622 |
| 1986 | 312 | 380 | 0 | 692 |
| 1987 | 526 | 379 | 3 | 908 |
| 1988 | 310 | 344 | 0 | 654 |
| 1989 | 350 | 488 | 1 | 839 |
| 1990 | 283 | 437 | 13 | 733 |
| 1991 | 303 | 316 | 0 | 619 |
| 1992 | 335 | 430 | 0 | 765 |
| 1993 | 616 | 656 | 0 | 1272 |
| 1994 | 464 | 740 | 0 | 1204 |
| 1995 | 425 | 497 | 0 | 922 |
| 1996 | 415 | 513 | 0 | 928 |
| 1997 | 159 | 580 | 0 | 739 |
| 1998 | 45 | 172 | 0 | 217 |
| 1999 | 36 | 77 | 0 | 113 |

### 12.1.2 South Africa's Patenting at the South African Patent Office

The South African Patent office works differently from the United States Patent Office. Patents are not examined in order to be granted by the South African Patent Office.

This by implication has the effect that the patents therefore is not necessarily novel, in relation to existing art. It does not necessary indicates a degree of inventiveness as is necessary to patent at the European or United States Patent Office. Since patenting at the USPTO is extremely expensive and only a very small number of South African patents are granted on a yearly basis, the possibility of making use of the South African patent office data was examined.

Finding reliable data on the South African patent database, specifically to find data on patents granted to South Africans proved to be a very frustrating and almost impossible task. Unlike the NBER database that exists for the USPTO, no such database exists at present for the South African Patent Office.

On acceptance of a patent by the patent office, the patent description is published in the South African Patent Journal. The patent is granted on the publication date of the appropriate issue of the Patent Journal. The Patent journal is published every month.

A file system with the patent journals scanned in (viewable only in pdf format) was obtained from Hahn & Hahn Patent attorneys. The patent journals (published monthly) for the period 1986 to 2004 were examined. All patent granted to a South African entity (priority country must be South Africa).

The ***priority country*** is the country where the patent is filed the first time. It is therefore assumed that the great majority of South Africans patenting will first patent in South Africa after which they might or might not patent their ideas in other countries. It is acknowledged that this approach has it's weaknesses, but still is the most simplified and the only feasible option to be able to search for South African patents in the South African Patent Journal.

This approach however also has it stronger points since by looking at patent published in the Patent Journal, only granted patents are taken into account. Although this is not examined, the process of self-elimination by patentees is used as a filter mechanism.

**Table 12-8: Patent data gathered from the South African Patent Office journal**

| | company | individual | university | government | Total |
|---|---|---|---|---|---|
| **1985** | 402 | 357 | 2 | 20 | 781 |
| **1988** | 410 | 471 | 1 | 16 | 898 |
| **1990** | 391 | 438 | 2 | 30 | 861 |
| **1993** | 364 | 374 | 3 | 27 | 768 |
| **1995** | 407 | 316 | 7 | 34 | 764 |
| **1998** | 431 | 385 | 19 | 22 | 857 |
| **2000** | 320 | 296 | 15 | 18 | 649 |
| **2001** | 353 | 355 | 16 | 14 | 738 |
| **2004** | 331 | 359 | 15 | 18 | 723 |

The following trends can be seen from the data gathered from the South African patent journal.

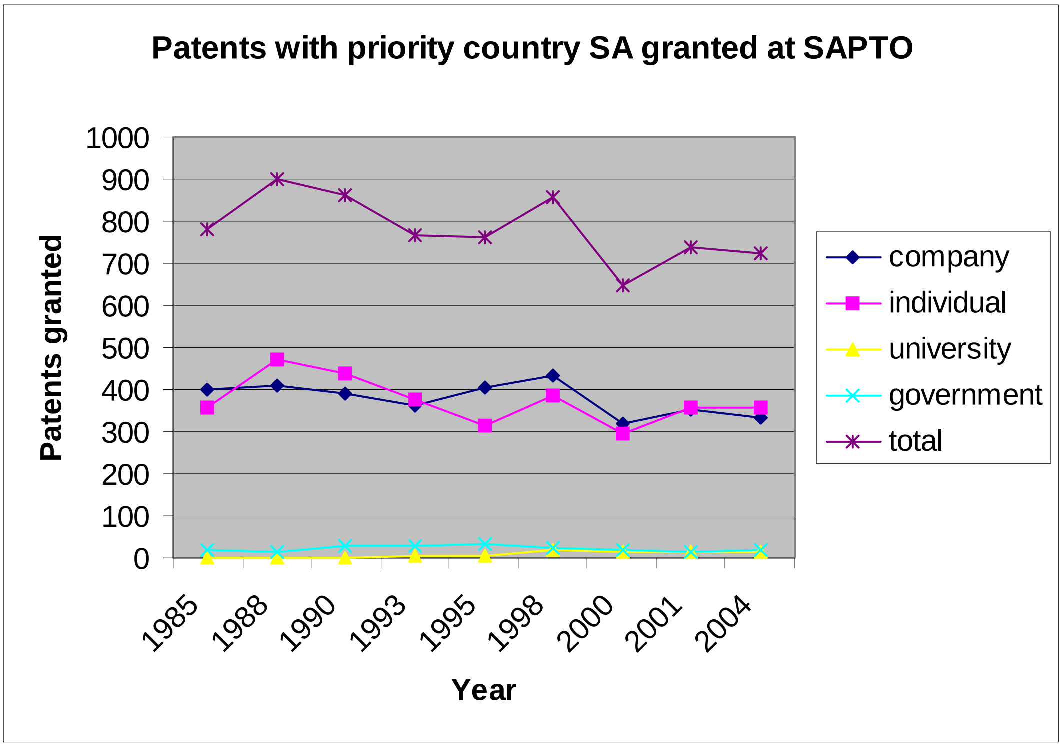


**Figure 12-1 Patents granted at the South African Patent Office**

## 12.2 South Africa's Publication data: Data gathering and Analysis

### 12.2.1 The Database of scientific papers originating from South Africa

A Database of all scientific papers in the ISI Web of science written by at least one author with a South African address was constructed from data. The database is constructed from text files downloaded from the ISI web of science database (Science Citation Index, Social Sciences Citation Index, Arts and Humanities Citation Index). These text files were then imported into an excel spreadsheet. The scientific publication was included in the database if the author's address or the Reprint address is a South African address.
The data was gathered from access to the ISI Web of science via the following organisations:

- Years 1987-2004 from Eindhoven University of Technology, Netherlands
- Years 1981-1986 from the Radboud University, Netherlands

The most important fields included in the data downloaded are listed in the following table.

**Table 12-9: Fields in Database of South African Scientific Output**

| Name of Field | Description |
|---|---|
| AU | Author names |
| TI | Title |
| SO | Journal Name |
| C1 | Author address: Addresses of authors writing scientific Publication |
| RP | Reprint address: Address where permission must be asked if the article is to be reprinted |
| CR | List of References made in the Journal |
| NR | Number of References made in the Journal |
| TC | Times Cited |
| PY | Publication Year |
| SC | Scientific Field |

Field important for the analysis of the data are the

- RP and CI (Reprint address and the Author's address): According to these addresses the paper is categorised into either the Higher Education sector, Public sector and the Private sector. In the case when the addresses referring to a specific scientific publication has two sectors, each sector is awarded a 0.5 publication.
- NR: The number of references to other scientific output from the scientific publication
- TC: Times the paper has been cited by another author publishing scientific output

### 12.2.2 Analysis of the scientific publication data in the database

An analysis is conducted on the database to establish the distribution of publication rates per year for the three sectors modelled in the model building study. In other words the sampling exercise is executed to find answers to the following questions:

*Q1: From the years 1981 to 2001 what was the amount of papers published in ISI journals by people from the Higher Education sector, Public sector and Private sector respectively?*

*Q2: From the years 1981 to 2001 what was the amount of references made in scientific publications created in the Higher Education sector, Public sector and Private sector respectively?*

Since the amount of papers included in the database is too large to analyse the information by examining every single record, a sampling strategy is followed. Since much variation in the address names exist, the safest option of obtaining and categorising the journals into one of the sectors, was through inspection of the addresses.

The error margin cannot be controlled for in these circumstances. Whereas by following the strategy of doing a sample on the data, we can get a pretty good idea of the inaccuracy introduced though the whole process.

### *Methodology*

A stratified random sample was taken from the database. In the Excel database, every 20$^{th}$ paper was extracted to a new “Sample database”. This led to the following number of papers being extracted to a second excel spreadsheet. The column with the “References in papers” is a summed total of the references made in the papers that have been sampled.

**Table 12-10: Sample taken for analysis of the distribution of Publications**

| Year | Total # Papers | Total # References made in papers | Stratified Random sample size |
|---|---|---|---|
| 1981 | 3075 | 39113 | 153 |
| 1982 | 3518 | 41868 | 175 |
| 1983 | 3581 | 43009 | 179 |
| 1984 | 3461 | 46950 | 173 |
| 1985 | 3968 | 56568 | 198 |
| 1986 | 4694 | 66769 | 234 |
| 1987 | 4758 | 66235 | 239 |
| 1988 | 4632 | 65301 | 231 |
| 1989 | 4183 | 62072 | 209 |
| 1990 | 3949 | 66850 | 197 |
| 1991 | 4134 | 73512 | 206 |
| 1992 | 4000 | 72629 | 200 |
| 1993 | 4195 | 73382 | 209 |
| 1994 | 4291 | 84125 | 214 |
| 1995 | 4503 | 85292 | 224 |
| 1996 | 4479 | 96584 | 224 |
| 1997 | 4398 | 100120 | 220 |
| 1998 | 4498 | 103269 | 225 |
| 1999 | 4755 | 112023 | 237 |
| 2000 | 4461 | 109612 | 223 |
| 2001 | 4691 | 122392 | 234 |
| **Total** | **88224** | **1587675** | **4404** |

The selected entries in the sample database was then categorised into the three sectors through the classification system as discussed in the Frascati manual:

- Higher Education sector (Universities and Technikons, Academic Hospitals etc.)
- Public sector (Science Councils, National Facilities)
- Private sector (Companies)

**Table 12-11: Results from the Sample**

| | # HES papers | # Pub papers | # Bus papers | | # HES references | # Pub references | # Bus references | |
|---|---|---|---|---|---|---|---|---|
| 1981 | 113 | 32 | 15 | | 1371 | 385 | 150 | |
| 1982 | 126 | 44 | 16 | | 1509 | 539 | 200 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1983 | 128 | 49 | 10 | | 1426 | 616 | 18 | |
| 1984 | 137 | 36 | 7 | | 1684 | 528 | 40 | |
| 1985 | 149 | 49 | 10 | | 2040 | 740 | 77 | |
| 1986 | 178 | 56 | 15 | | 3031 | 798 | 71 | |
| 1987 | 189 | 64 | 6 | | 2359 | 571 | 41 | |
| 1988 | 192 | 54 | 7 | | 2596 | 740 | 23 | |
| 1989 | 164 | 59 | 4 | | 2557 | 908 | 19 | |
| 1990 | 155 | 51 | 8 | | 2562 | 704 | 89 | |
| 1991 | 166 | 50 | 11 | | 2878 | 910 | 46 | |
| 1992 | 168 | 42 | 8 | | 3564 | 468 | 120 | |
| 1993 | 176 | 42 | 8 | | 3286 | 572 | 90 | |
| 1994 | 174 | 47 | 8 | | 3133 | 412 | 174 | |
| 1995 | 191 | 42 | 10 | | 3175 | 585 | 114 | |
| 1996 | 177 | 52 | 14 | | 4129 | 1301 | 126 | |
| 1997 | 179 | 44 | 18 | | 3785 | 678 | 144 | |
| 1998 | 172 | 52 | 13 | | 3854 | 1068 | 237 | |
| 1999 | 188 | 43 | 21 | | 4857 | 1006 | 309 | |
| 2000 | 180 | 45 | 16 | | 4781 | 1008 | 273 | |
| 2001 | 202 | 35 | 11 | | 5004 | 804 | 86 | |

The Margin of error is computed through the following computation:

By taking a stratified sample, the effective sample size is increased by a factor between $n/0.8$ to $n/0.9$ if $n$ denotes the sample size.

Since the sample size is 4404, and taking the design effect computation to be $n/0.85$ the effective sample size ($N$) therefore is 5181. To compute the margin of error the following equation is used (Page and Meyer, 2000):

Margin of error = $2*\sqrt{\frac{p(p-1)}{N}}$

Die margin of error is therefore computed to make use of the most conservative value for $p = 0.5$. This results in a Margin of 0.0139 or approximately 1%.

From the sample analysis, the percentage of papers created in the three sectors is computed. The same is done for the percentage of references made in the papers.

**Table 12-12: Distribution of scientific paper output and reference counts**

| | **HES % papers** | **Pub % papers** | **Bus % papers** | | **HES % references** | **Pub % references** | **Bus % references** | |
|---|---|---|---|---|---|---|---|---|
| 1981 | 0.72 | 0.19 | 0.09 | | 0.72 | 0.20 | 0.08 | |
| 1982 | 0.68 | 0.23 | 0.09 | | 0.67 | 0.24 | 0.09 | |
| 1983 | 0.69 | 0.26 | 0.05 | | 0.69 | 0.30 | 0.01 | |
| 1984 | 0.77 | 0.19 | 0.04 | | 0.75 | 0.23 | 0.02 | |
| 1985 | 0.73 | 0.23 | 0.04 | | 0.71 | 0.26 | 0.03 | |
| 1986 | 0.73 | 0.21 | 0.05 | | 0.78 | 0.20 | 0.02 | |
| 1987 | 0.75 | 0.23 | 0.02 | | 0.79 | 0.19 | 0.01 | |
| 1988 | 0.78 | 0.19 | 0.03 | | 0.77 | 0.22 | 0.01 | |
| 1989 | 0.74 | 0.24 | 0.02 | | 0.73 | 0.26 | 0.01 | |
| 1990 | 0.74 | 0.22 | 0.04 | | 0.76 | 0.21 | 0.03 | |
| 1991 | 0.75 | 0.20 | 0.05 | | 0.75 | 0.24 | 0.01 | |
| 1992 | 0.79 | 0.17 | 0.04 | | 0.86 | 0.11 | 0.03 | |
| 1993 | 0.80 | 0.17 | 0.03 | | 0.83 | 0.14 | 0.02 | |
| 1994 | 0.78 | 0.19 | 0.03 | | 0.84 | 0.11 | 0.05 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1995 | 0.81 | 0.15 | 0.04 | | 0.82 | 0.15 | 0.03 | |
| 1996 | 0.74 | 0.21 | 0.05 | | 0.74 | 0.23 | 0.02 | |
| 1997 | 0.76 | 0.17 | 0.08 | | 0.82 | 0.15 | 0.03 | |
| 1998 | 0.74 | 0.21 | 0.05 | | 0.75 | 0.21 | 0.05 | |
| 1999 | 0.77 | 0.16 | 0.08 | | 0.79 | 0.16 | 0.05 | |
| 2000 | 0.77 | 0.17 | 0.06 | | 0.79 | 0.17 | 0.05 | |
| 2001 | 0.84 | 0.12 | 0.04 | | 0.85 | 0.14 | 0.01 | |

The next step now is to apply these findings to the total population to get an estimation of the total papers produced in the different sectors by year from 1981 to 2001. The percentages computed and displayed in Table 12-12: is used to find an estimate of how many papers were created in a sector for the whole population.

**Table 12-13: Scientific paper publication counts and reference counts**

| | HES papers | Pub papers | Bus papers | | HES references | Pub references | Bus references | |
|---|---|---|---|---|---|---|---|---|
| 1981 | 2214 | 584 | 277 | | 28161 | 7823 | 3129 | |
| 1982 | 2392 | 809 | 317 | | 28052 | 10048 | 3768 | |
| 1983 | 2471 | 931 | 179 | | 29676 | 12903 | 430 | |
| 1984 | 2665 | 658 | 138 | | 35213 | 10799 | 939 | |
| 1985 | 2897 | 913 | 159 | | 40163 | 14708 | 1697 | |
| 1986 | 3427 | 986 | 235 | | 52080 | 13354 | 1335 | |
| 1987 | 3569 | 1094 | 95 | | 52326 | 12585 | 662 | |
| 1988 | 3613 | 880 | 139 | | 50282 | 14366 | 653 | |
| 1989 | 3095 | 1004 | 84 | | 45313 | 16139 | 621 | |
| 1990 | 2922 | 869 | 158 | | 50806 | 14039 | 2006 | |
| 1991 | 3101 | 827 | 207 | | 55134 | 17643 | 735 | |
| 1992 | 3160 | 680 | 160 | | 62461 | 7989 | 2179 | |
| 1993 | 3356 | 713 | 126 | | 60907 | 10273 | 1468 | |
| 1994 | 3347 | 815 | 129 | | 70665 | 9254 | 4206 | |
| 1995 | 3647 | 675 | 180 | | 69939 | 12794 | 2559 | |
| 1996 | 3314 | 941 | 224 | | 71472 | 22214 | 1932 | |
| 1997 | 3342 | 748 | 352 | | 82098 | 15018 | 3004 | |
| 1998 | 3329 | 945 | 225 | | 77452 | 21686 | 5163 | |
| 1999 | 3661 | 761 | 380 | | 88498 | 17924 | 5601 | |
| 2000 | 3435 | 758 | 268 | | 86593 | 18634 | 5481 | |
| 2001 | 3940 | 563 | 188 | | 104033 | 17135 | 1224 | |

It is clear from the data that the Business sector makes a much smaller contribution in terms of scientific paper output than the HES or Public sector. For this reason the production of paper in the Business sector is not included in the model.

### 12.2.3 The Depreciation of knowledge

Adams (1990) developed a production function model to measure the impact of ‘fundamental stocks of knowledge’ productivity growth at the sectoral level. In this model he makes use of stocks of publication data. Adams also made use of an accumulated stock of knowledge in his model.

$$N_t = N_{t-1}(1-\delta) + P_t \qquad \textbf{12-1}$$

where N stands for the stock of knowledge in period t (or t-1), $\delta$ is a depreciation factor (estimated to be equal to 0.13), and P is the number of papers published in year t.

In a study conducted by Cabellero and Jaffe, the found that the rate of ideas' obsolescence has increased from 3% in the 1900's to up to 12% in 1990. This percentage is also close to the estimated value form Adams' (1990) study.

The depreciation rate is also used for the rates of depreciation of stocks of knowledge in the model developed in this study. As citation data is available for the South African papers, it is used to check this estimation for the purpose of this model.

The citation pattern of the Papers generated in South Africa is investigated. This analysis is done from the database of papers generated in South Africa. It is assumed that the citation pattern can be used for the papers generated in all the sectors. i.e. it is assumed that the difference in citation patterns between sectors is negligible.

**Table 12-14: Citations received by South African Scientific journals.**

| | # Papers | # citations received | avg # citations received per paper |
|---|---|---|---|
| 1981 | 3075 | 25229 | 8.20 |
| 1982 | 3518 | 29365 | 8.35 |
| 1983 | 3581 | 27855 | 7.78 |
| 1984 | 3461 | 28404 | 8.21 |
| 1985 | 3968 | 31722 | 7.99 |
| 1986 | 4694 | 35210 | 7.50 |
| 1987 | 4758 | 34459 | 7.24 |
| 1988 | 4632 | 35926 | 7.76 |
| 1989 | 4183 | 31896 | 7.63 |
| 1990 | 3949 | 36425 | 9.22 |
| 1991 | 4134 | 36418 | 8.81 |
| 1992 | 4000 | 33066 | 8.27 |
| 1993 | 4195 | 33580 | 8.00 |
| 1994 | 4291 | 33835 | 7.89 |
| 1995 | 4503 | 33971 | 7.54 |
| 1996 | 4479 | 31217 | 6.97 |
| 1997 | 4398 | 29101 | 6.62 |
| 1998 | 4498 | 29776 | 6.62 |
| 1999 | 4755 | 27818 | 5.85 |
| 2000 | 4461 | 23627 | 5.30 |
| 2001 | 4691 | 20726 | 4.42 |
| 2002 | 5068 | 14893 | 2.94 |
| 2003 | 4990 | 9553 | 1.91 |

When the data is presented as a curve the following can be seen.

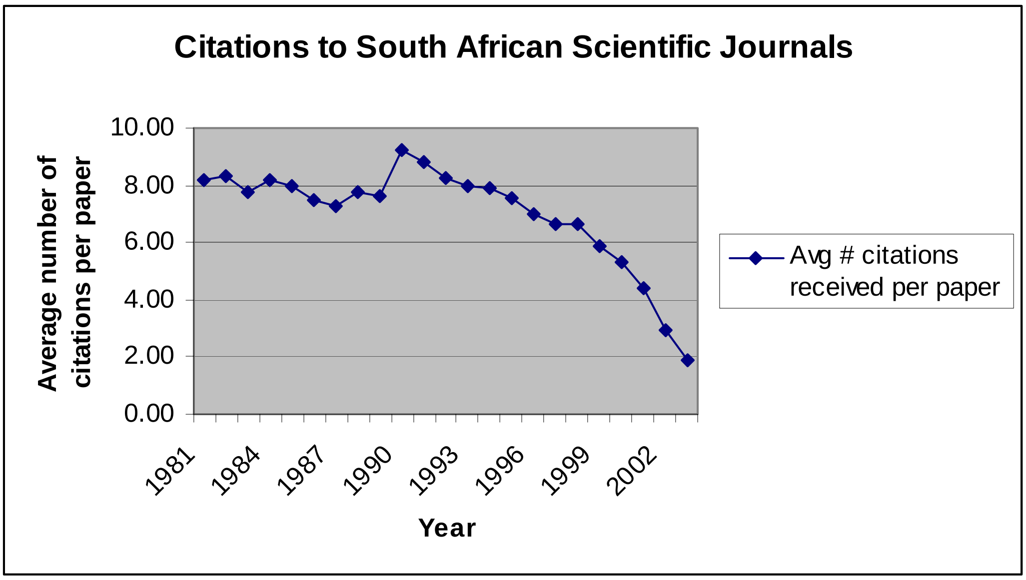


**Figure 12-2 Citations to South African scientific papers and journals**

It seems that the citations curve reaches an average maximum at around 1994 to 1992. From 2005 this is about 10 to 13 years. It can therefore be concluded that the estimation from Adams' model is a realistic assumption for the system.

From this reasoning the paper citation graph for South African scientific papers is therefore used to estimate an average period scientific knowledge remains relevant to the scientific community. The time knowledge remains relevant is approximated to be about 10 years (after which the citation curve seems to flatten).

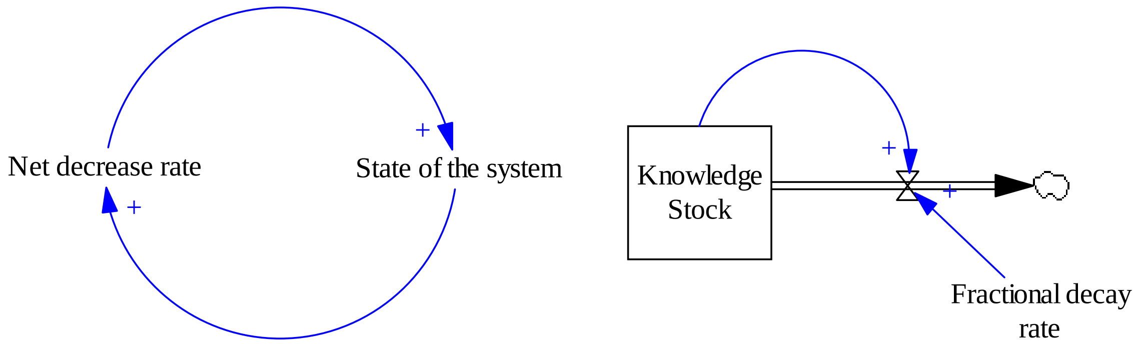


**Figure 12-3 Dynamic structure of the decay of knowledge**

The decay rate of knowledge is modelled through a first order material delay.

Outflow = Knowledge Stock/AT, where AT is the average delay time.

# 13 APPENDIX B

## 13.1 Inputs to R&D

The Frascati manual is devoted to measuring R&D inputs. This includes formal R&D in formal R&D units as well as informal or occasional R&D in other units. For statistical purposes the following R&D inputs are measured (OECD, 2002:20):

- Full-time-equivalent or person years spent on R&D
- Expenditures for R&D performed within a statistical unit or sector in the economy (Intramural expenditures).
    - Current costs: labour costs and other current costs.
    - Capital expenditures: annual gross expenditures on gross fixed assets.
- Extramural expenditures, which cover payment of R&D performed outside the statistical unit sector.

R&D is an activity involving significant transfers of resources among units, organisations and sector (especially between government and other performers). The aim of the Frascati manual is to establish specifications for R&D input data and therefore to establish specifications for the collection of the data.

In order to facilitate the collection of data, the description of flows of R&D funds and the interpretation of R&D data, the data gathered from reporting units (units from where data is collected) are grouped into sectors of the economy (OECD, 2002:53). The sectors the aggregates for R&D data is grouped and includes the following:

- Business enterprise sector
- Government
- Private non-profit
- Higher education
- Abroad

International aggregate expenditure comparisons are done on the gross domestic expenditure on R&D (GERD) performed on national territory in a given year. This includes R&D financed from abroad but excludes R&D funds performed abroad.

### 13.1.1 Types of research

In the description of the South African R&D system, reference will be made to different types of R&D performed within different sectors. These concepts are therefore shortly defined as in the Frascati manual (OECD, 2002 a):

***Basic Research*:** Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.

*Pure Basic Research* is carried out for the advancement of knowledge without seeking long-term economic or social benefits or making any effort to apply the results to practical problems or to transfer the results to sectors responsible for their application.\

*Oriented Basic Research (Strategic Research)* is carried out with the expectation that it will produce a broad base of knowledge likely to form the basis of the solution to recognised or expected, current or future problems or possibilities.

***Applied Research:*** Applied research is an original investigation undertaken in order to acquire new knowledge. It is however, directed primarily towards a specific practical aim or objective.

***Experimental Development:*** Experimental development is systematic work, drawing on knowledge gained from research and practical experience that is directed to new processes, systems and services; or to improving substantially those already produced or installed.

### 13.1.2 Measurement of R&D output

The reason interest in R&D depends more on the social and economic effects through the acquisition of new knowledge than on the activity itself. R&D output indicators are far more complicated to determine, define and produce.

The Output of R&D or science and technology (S&T) in general can be measured in several ways (OECD, 2002 a):

- Innovation surveys or existing data sources are methods of measuring the effects of the innovation process of which R&D plays an important role.
- Existing data sources such as bibliometrics, patent data, and the analysis of trade data in terms of "technology intensity" of products or industries concerned.

There has been only one Oslo-type innovation survey carried out by the University of Pretoria in co-operation with the Eindhoven University of Technology in the Netherlands (Oerlemans L. A. G., Pretorius M. W. et al, 2003)

Since time series data is important for the successful completion of the study, R&D outputs will be measured through existing data sources. The use of these sources is however not without problems. The following sections deals with limitations of the use of these indicators.

### 13.1.3 South African Frascati style R&D surveys

Blankley and Kahn (2005) published a paper on the history of South Africa's Frascati style surveys. The following sector discusses the methodological issues and measurement issues that exist in the time series data of the SA R&D survey data as well as the measurement of R&D in general.

***Definition has expanded***

Blankley and Kahn (2005) published a paper on the history of South Africa's Frascati style surveys. R&D is not as well defined and it is not easy to establish its boundaries as one would like to have it. There is a global debate about what qualifies as R&D;

this debate shifts as global changes occur regarding economic activity. Changes have occurred in the definition of R&D over the past 30 years. Where it was mainly hard technologies that were measured about 30 years ago, the measurement The definition has been expanded in some instances from only including 30 years ago only hard technologies now also includes services and software development.

***Who does the reporting?***

Measurement of the R&D is also influenced by who does the reporting. Researchers, managers and financial people are unlikely to report the same estimates of R&D spending – they all have different approaches. This may also influence the accuracy with which the survey is conducted.

*South Africa's R&D surveys and changes in methodology*

South Africa has been conducting Frascati-style R&D surveys since shortly after the first manual was released in 1963 (Boshoff *et al*, 2003). The first R&D survey based on OECD guidelines was conducted in 1966 and over the next 25 years up to 1993/4, South Africa conducted 18 regular official surveys. Social sciences R&D expenditure have only been included in the survey since 1977/78

The CSIR in partnership with the HSRC started to conducted survey fieldwork. The survey has been conducted under the auspices of different bodies until 1991.

- The CSIR conducted the R&D survey for Natural sciences
- The HSRC was responsible for the gathering of data for social sciences from 1977/8.

In general the 1991/2 survey was more thorough than the surveys from prior years. 57% increase in R&D expenditure from 1989/90 to 1991/2 in comparison with an increase of 34% between 1987/8 to 1989/90. This is largely so because of the companies surveyed. The register with the businesses surveyed in the Business sector was revised and populated with 44% more enterprises than the 1989 survey. Defence organisations were also included in the survey which was not included in the 1989 survey. The defence R&D expenditure made up roughly 15% of the R&D budget in 1991.

The CSIR in partnership with the HSRC started to conducted survey fieldwork. The survey has been conducted under the auspices of different bodies until 1991. The survey was put open on tender from after 1991/2. After 1991 it was of lower priority to the state resulting in the 1993 and 1997 tenders were being awarded to private consultancies. Kahn (2004) comments on the inconsistency in the time series data after 1991 as follows: "Unfortunately instability after 1991 led to the conduct of the Survey migrating across a number of agencies with consequent inconsistency of methodology, gaps in the time series; and loss of institutional memory and capacity. However the Surveys are the only series of R&D data and therefore must be used. In addition to the Frascati data one has higher education, grant maker and bibliometric databases that can be used to corroborate evidence."

The survey was carried out on biannual basis until 1993/4. No survey was carried out in the 1995/6 (possibly because of the National Research and Technology Audit) or

1999/2000 cycles, leaving gaps in the time series data (HSRC, 2003: 211; Boshoff, 2003). The 1993/4 and 1997/8 R&D surveys used a different methodology from the R&D surveys conducted in the past. The survey was handed over to a private consultant for the 1993/4 and 1997/8 survey years. In the 1993/4 R&D surveys a similar approach of previous years were followed. Yet more companies were added to the register of companies surveyed. Pouris (2006) states that the 1993/4 and 1997/8 methodology is comparable to the methodology used in the previous years when considering the data gathered for the Private and Public sector. The main methodological differences in the surveys exist for the 1997/8 survey with regards to the Higher Education Sector.

Up to 1997 SAPSE data was used for the calculation of HR data in the HES. Higher Education institutions were also surveyed regarding the time spent on R&D and R&D expenditure in these institutions. In the 1997 survey another approach was followed. The SAPSE data was utilised but the percentage time spent by researchers on R&D was estimated by making use of research coefficients. Universities were arranged in high, medium and low intensity groups. Research coefficients were used to estimate the research time spent in these institutions as well as the R&D expenditure in these institutions. In some instances the Non-profit and Public sector is combined as the Services sector. This however does not have a big impact since the non-profit sector makes a very small contribution to R&D expenditure.

Pouris states the following regarding the 1993/4 and 1997/8 surveys: "During the surveys I supervised dip-stick surveys were undertaken of the remaining enterprises in order to identify new-comers. Each time approximately 1000 enterprises were approached. Businesses are included according to various criteria, namely:
1) on the basis that they were included in previous surveys,
2) if they received R&D funds from government programmes,
3) they are identified by respondents as contractors of research
4) have been identified by journals, popular press etc as undertaking R&D. "

Mouton (2001:44) reports a suspicion that the 1997/8 R&D survey might underestimate R&D spending in South Africa.

No survey was carried out in the 1995/6 (possibly because of the National Research and Technology Audit) or 1999/2000 cycles, leaving gaps in the time series data (HSRC, 2003: 211). Another inconsistency with the methodology followed in the 1997/8 R&D Survey is that it does not discriminate between the Non-profit and Public sector.

For the years 2001/2 R&D survey, the responsibility of executing the survey was handed to the HSRC. The methodology followed in these surveys is comparable to that followed in the 1991 survey. The Higher Education sector was again fully surveyed as with the pre-1997 surveys.

Again the register with businesses has been updated with more businesses known to conduct R&D. In the 2001/2 survey a number of 139 Business BERD questionnaires were received back. The register was increased and 2003/4 a number of 339 non-nil response BERD questionnaires were received.

It can however be argued that although the increase in businesses surveyed no doubt leads to a potentially more accurate survey, the top 20 business sector performers accounted for 79% of business expenditure. Therefore we can conclude that a change in the size of the sample will add to accuracy but that the general level of R&D expenditure should not be affected too much.

We can therefore conclude from this discussion that there were some methodological changes in the surveys. Concentration however aids in the accuracy of the different surveys.

There are definite methodological inconsistencies in the survey method for the Higher Education Sector over the time period in consideration. For this reason the Higher Education Sector model does not make use of the Survey data, but makes use of HEMIS data in terms of Academic and Research staff employed in the system.

### 13.1.4 The HEMIS data base

A telephonic interview was conducted with Jean Skene the director of HEMIS at the Department of Education on 14 March 2006. In this interview it was formally confirmed that the comparison of the data in the HEMIS database between different years is appropriate.

The data is gathered from the Higher Education Institutions with the categories of the human resources identified as by the Department of Education. The definitions of the fields of data gathered from the Higher Education institutions remained consistent over the time period in consideration. No changes in definitions of the HR component have been made in the time series data.

From 1986 to 1998 Public Higher Education Institutions were required to submit data in the format of aggregated tables for headcounts, graduates and full time equivalent students and staff as specified by the Department of Education. The submission of data was stream lined in 1999: From 1999 the Public Higher Education Institutions were required to submit unit record databases for students and staff. These institutional databases are then loaded into a National database from which the Department of Education generates the aggregated tables.

From this can therefore be concluded that the use of time series data in the HEMIS database is therefore appropriate for the purpose of this study.

## 13.2 The Higher Education Sector

### 13.2.1 R&D Expenditure in the HES

R&D Survey data is gathered from the R&D Surveys (1977 to 2003). The following table reflects figures for R&D spending in the Higher Education sector. This is referred to in the main body of the thesis.

**Table 13-1: Sector Source funding (Financiers) of the HES**

| Year | HES (R) | Public sector (R) | Private sector (R) |
|---|---|---|---|
| 1977 | 30126000 | 8196000 | 1909000 |
| 1979 | 47409000 | 10222000 | 2903000 |
| 1981 | 72671136 | 15263000 | 5408000 |
| 1983 | 120989000 | 17489000 | 10403000 |
| 1985 | 239731000 | 40818000 | 22346000 |
| 1987 | 261135000 | 43874000 | 31151000 |
| 1989 | 406693000 | 56570000 | 51742000 |
| 1991 | 552457000 | 68914000 | 65882000 |
| 1993 | 336708000 | 46462000 | 29574000 |
| 1995 | N/A | N/A | N/A |
| 1997 | 406000000 | 33000000 | 57000000 |
| 1999 | N/A | N/A | N/A |
| 2001 | 581560000 | 1187075000 | 380075000 |
| 2003 | 346132000 | 848,554,000 | 478734000 |

**Table 13-2: R&D expenditure in the Higher Education sector**

| Year | R&D investment (R) | Expenditure HR | % Expenditure HR | Expenditure on Capital | % Expenditure on Capital |
|---|---|---|---|---|---|
| 1977 | 40944000 | 20481000 | 50.02% | 2311000 | 5.64% |
| 1979 | 62109000 | 33306000 | 53.63% | | 0.00% |
| 1981 | 94424210 | 34053000 | 36.06% | 5618240 | 5.95% |
| 1983 | 151352000 | 53124000 | 35.10% | 5985000 | 3.95% |
| 1985 | 306534000 | 173232000 | 56.51% | 13496000 | 4.40% |
| 1987 | 339194000 | 175463000 | 51.73% | 14826000 | 4.37% |
| 1989 | 517566000 | 258324000 | 49.91% | 35879000 | 6.93% |
| 1991 | 690439000 | 341904000 | 49.52% | 30062000 | 4.35% |
| 1993 | 415648000 | 230435000 | 55.44% | 15669000 | 3.77% |
| 1995 | N/A | N/A | N/A | N/A | N/A |
| 1997 | 496000000 | 253100000 | 51.03% | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A |
| 2001 | 1896156000 | 1127710000 | 59.47% | 115953000 | 6.12% |
| 2003 | 2071351000 | 925255000 | 44.67% | 162380000 | 7.84% |
| **Average** | | | 49.42% | Average | 4.85% |
| **Standard Deviation** | | | 7.51% | St Dev | 2.07% |

**Table 13-3: R&D expenditure on Human resources in the HES**

| Year | Total HR Spending (R'000) | Researcher (R'000) | % | Technicians (R'000) | % | Support (R'000) | % |
|---|---|---|---|---|---|---|---|
| 1977 | 20480 | 17721 | 86.53% | 2232 | 10.90% | 527 | 2.57% |
| 1979 | 33306 | 28014 | 84.11% | 4445 | 13.35% | 847 | 2.54% |
| 1981 | 34052 | 25814 | 75.81% | 6903 | 20.27% | 1335 | 3.92% |
| 1983 | 53124 | 43357 | 81.61% | 7715 | 14.52% | 2052 | 3.86% |
| 1985 | 173232 | 146712 | 84.69% | 17995 | 10.39% | 8525 | 4.92% |
| 1987 | 175463 | 159281 | 90.78% | 10783 | 6.15% | 5399 | 3.08% |
| 1989 | 258324 | 225510 | 87.30% | 25230 | 9.77% | 7584 | 2.94% |
| 1991 | 341904 | 323377 | 94.58% | 13179 | 3.85% | 5348 | 1.56% |
| 1993 | 230435 | 220381 | 95.64% | 5734 | 2.49% | 4320 | 1.87% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1997 | 253100 | 240445 | 95.00% | 7593 | 3.00% | 5062 | 2.00% |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 1127710 | 1071325 | 95.00% | 33831 | 3.00% | 22554 | 2.00% |
| **Average** | | | 88.28% | | 8.88% | | 2.84% |
| **Standard Deviation** | | | 6.52% | | 5.76% | | 1.04% |

**Table 13-4: R&D spending on type of research**

| Year | R&D investment (R'000) | Basic Research (R'000) | % | Applied Research (R'000) | % | Experimental Development (R'000) | % |
|---|---|---|---|---|---|---|---|
| 1979 | 62109 | 35598 | 57.32 % | 22289 | 35.89 % | 4757 | 7.66% |
| 1981 | 94424 | 50381 | 53.36 % | 36807 | 38.98 % | 7325 | 7.76% |
| 1983 | 151352 | 83124 | 54.92 % | 56200 | 37.13 % | 12027 | 7.95% |
| 1985 | 306534 | 170941 | 55.77 % | 107237 | 34.98 % | 28357 | 9.25% |
| 1987 | 339194 | 176415 | 52.01 % | 132168 | 38.97 % | 30612 | 9.02% |
| 1989 | 517566 | 242332 | 46.82 % | 210725 | 40.71 % | 64508 | 12.46 % |
| 1991 | 690439 | 359788 | 52.11 % | 273757 | 39.65 % | 56895 | 8.24% |
| 1993 | 415648 | 207319 | 49.88 % | 172351 | 41.47 % | 35978 | 8.66% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | 496000 | N/A | 49.80 % | N/A | 38.00 % | N/A | 12.20 % |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 1896156 | 862067 | 45.46 % | 706108 | 37.24 % | 234529 | 12.37 % |
| 2003 | 2071351 | 915971 | 44.22 % | 827,209 | 39.94 % | 328170 | 15.84 % |
| **Average** | 51.06% | | 38.45 % | | 10.13 % | | |
| **Standard Deviation** | 4.27% | | 2.01% | | 2.68% | | |

## 13.2.2 Human Resources in the HES

The Following table reflects figures for the FTE researchers employed in the Higher Education system. From the figures can be seen that by far the greatest share of FTE research personnel are FTE researchers.

**Table 13-5: Human Resource data from the R&D Surveys**

| | Total HC | HC Researchers | % | HC Technicians | % | HC Support | % |
|---|---|---|---|---|---|---|---|
| 1977 | 6425 | 5053 | 78.65% | 926 | 14.41% | 446 | 6.94% |
| 1979 | 8181 | 6406 | 78.30% | 1272 | 15.55% | 503 | 6.15% |
| 1981 | 6116 | 4044 | 66.12% | 1456 | 23.81% | 616 | 10.07% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1983 | 11465 | 8841 | 77.11% | 1523 | 13.28% | 1101 | 9.60% |
| 1985 | 17889 | 13588 | 75.96% | 2156 | 12.05% | 2145 | 11.99% |
| 1987 | 19943 | 15417 | 77.31% | 1645 | 8.25% | 2881 | 14.45% |
| 1989 | 19682 | 13978 | 71.02% | 2758 | 14.01% | 2946 | 14.97% |
| 1991 | 16514 | 14540 | 88.05% | 962 | 5.83% | 1012 | 6.13% |
| 1993 | 10835 | 9916 | 91.52% | 511 | 4.72% | 408 | 3.77% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 15767 | 12626 | 80.08% | 827 | 5.25% | 2314 | 14.68% |
| 2003 | 19377 | 14055 | 72.53% | 2594 | 13.39% | 2728.5 | 14.08% |
| **Average** | | | 77.88% | | 11.87% | | 10.26% |
| **Standard Deviation** | | | 7.17% | | 5.62% | | 4.06% |

**Table 13-6: Full time equivalent researchers in the HES**

| **Year** | **Amount of R&D workers (FTE)** | **FTE Researchers** | **%** | **FTE Technicians** | **%** | **FTE Support Personnel** | **%** |
|---|---|---|---|---|---|---|---|
| 1977 | 2555 | 1938 | 75.85% | 447 | 17.50% | 170 | 6.65% |
| 1979 | 3216 | 2399 | 74.60% | 623 | 19.37% | 194 | 6.03% |
| 1981 | 2253 | 1425 | 63.25% | 627 | 27.83% | 200 | 8.88% |
| 1983 | 4128 | 3384 | 81.98% | 532 | 12.89% | 212 | 5.14% |
| 1985 | 6810 | 5183 | 76.11% | 928 | 13.63% | 699 | 10.26% |
| 1987 | 6610 | 5780 | 87.44% | 473 | 7.16% | 357 | 5.40% |
| 1989 | 6353 | 5160 | 81.22% | 837 | 13.17% | 355 | 5.59% |
| 1991 | 6533 | 5984 | 91.60% | 289 | 4.42% | 260 | 3.98% |
| 1993 | 4450 | 4096 | 92.04% | 234 | 5.26% | 120 | 2.70% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | 4693 | N/A | N/A | N/A | N/A | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 4042 | 3425 | 84.74% | 217 | 5.37% | 401 | 9.92% |
| 2003 | 4553.99 | 3373.78 | 74.08% | 763.33 | 16.76% | 416.88 | 9.15% |
| **Average** | | | 80.26% | | 13.03% | | 6.70% |
| **Standard Deviation** | | | 8.60% | | 7.22% | | 2.51% |

**Table 13-7: Data from HEMIS database for years 1986 to 2003**[1]

| | **Academic and Research Personnel** | **Professional Personnel** | **Total Personnel at Universities** |
|---|---|---|---|
| 1986 | 9271 | 11232 | 29061 |
| 1987 | 9392 | 11368 | 30362 |
| 1988 | 9665 | 11697 | 31261 |
| 1989 | N/A | N/A | N/A |
| 1990 | 9615 | 11614 | 32618 |
| 1991 | 9971 | 12181 | 33855 |
| 1992 | 10211 | 12501 | 33819 |
| 1993 | 10357 | 12758 | 33864 |
| 1994 | 10268 | 12720 | 33745 |
| 1995 | 10489 | 12994 | 34181 |
| 1996 | 10567 | 13263 | 34368 |

[1] Data from the universities of Transkei, Northwest and Venda are not included as they are not available in the HEMIS database. Durban Westville is not included for 1990.

| | | | |
|---|---|---|---|
| 1997 | 10774 | 13606 | 34400 |
| 1998 | 10415 | 13108 | 32525 |
| 1999 | N/A | N/A | N/A |
| 2000 | 10390 | 13460 | 31226 |
| 2001 | 10010 | 13028 | 28482 |
| 2002 | 10552 | 13686 | 30048 |
| 2003 | 10641 | 13977 | 30211 |

**Table 13-8: HEMIS data of Ageing if the researchers**

| | < 25 | 25 - 34 | 35 - 44 | 45 – 54 | 55 + |
|---|---|---|---|---|---|
| 1986 | 138 | 2502 | 3284 | 2307 | 1039 |
| 1987 | 116 | 2364 | 3387 | 2447 | 1078 |
| 1988 | 104 | 2452 | 3346 | 2666 | 1097 |
| 1989 | 117 | 2393 | 3340 | 2650 | 1084 |
| 1990 | 129 | 2383 | 3494 | 2831 | 1171 |
| 1991 | 97 | 2255 | 3438 | 2941 | 1240 |
| 1992 | 97 | 2197 | 3477 | 3077 | 1363 |
| 1993 | 96 | 2109 | 3593 | 3219 | 1340 |
| 1994 | 88 | 2071 | 3558 | 3212 | 1339 |
| 1995 | 122 | 2220 | 3708 | 3333 | 1522 |
| 1996 | 140 | 2236 | 3667 | 3356 | 1618 |
| 1997 | 141 | 2265 | 3793 | 3380 | 1670 |
| 1998 | 86 | 2138 | 3486 | 3292 | 1658 |
| 1999 | NA | NA | NA | NA | NA |
| 2000 | 174 | 2392 | 3500 | 3525 | 1524 |
| 2001 | 177 | 2120 | 3036 | 3084 | 1373 |
| 2002 | 195 | 2367 | 3415 | 3563 | 1680 |
| 2003 | 151 | 2329 | 3404 | 3631 | 1747 |

### 13.2.3 Students in the Higher Education system

The following table documents data in Student enrolment in the South African Higher Education System (Universities only) gathered from two main sources namely:

- "1990 SA science and technology indicators" for years 1980 - 1988 (FRD, 1990).
- HEMIS database for years 1986 to 2003 (HEMIS, 2005)

The Model input column reflects the values used as model input by integration of the two sources.

**Figure 13-1 Students in the Higher Education sector**

| | Student Numbers (HEMIS, 2005) | Student Numbers (FRD, 1990) | Model input |
|---|---|---|---|
| 1980 | | 152346 | 144000 |
| 1981 | | 154833 | 154000 |
| 1982 | | 158834 | 164000 |
| 1983 | | 173116 | 174000 |
| 1984 | | 185261 | 184000 |
| 1985 | | 211756 | 198000 |
| 1986 | 211593 | 233625 | 211593 |
| 1987 | 223720 | 247694 | 223720 |
| 1988 | 242067 | 267608 | 242067 |
| 1989 | 257355 | | 257355 |

| | | | |
|---|---|---|---|
| 1990 | 270399 | | 270399 |
| 1991 | 282779 | | 282779 |
| 1992 | 310384 | | 310384 |
| 1993 | 318517 | | 318517 |
| 1994 | 338470 | | 338470 |
| 1995 | 361371 | | 361371 |
| 1996 | 379825 | | 379825 |
| 1997 | 412795 | | 412795 |
| 1998 | 421316 | | 421316 |
| 1999 | 431478 | | 431478 |
| 2000 | 439810 | | 439810 |
| 2001 | 426684 | | 426684 |
| 2002 | 440204 | | 440203.9 |
| 2003 | 435567 | | 435567.4 |

The following is a graphical representation of the data presented in the table above, including the approximation of an integration of the two datasets, which is used as an input to the model.

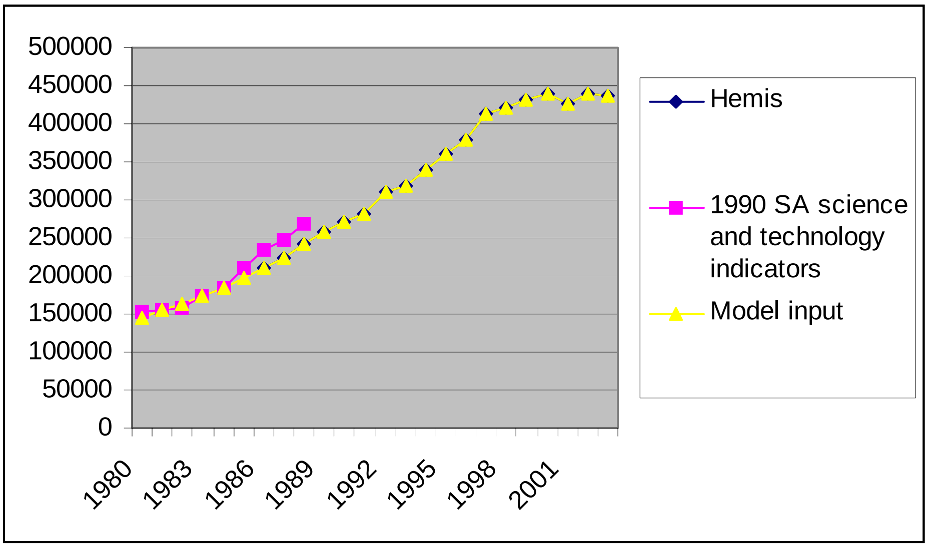


**Figure 13-2 Student enrolment in South Africa's HES**

### 13.2.4 The Student-Staff relationship

**Figure 13-3 Student-to-staff relationship at HAU[2] and HDU[3] in South Africa**

| | HAU | HDU |
|---|---|---|
| 1986 | 26.15 | 21.49 |
| 1987 | 27.33 | 24.15 |
| 1988 | 27.69 | 30.24 |
| 1989 | 28.15 | 34.49 |
| 1990 | 28.62 | 38.74 |
| 1991 | 30.46 | 35.38 |

[2] HAU – Historically Advantaged Universities
[3] HDU – Historically Disadvantaged Universities

| | | |
|---|---|---|
| 1992 | 31.22 | 34.10 |
| 1993 | 32.10 | 32.57 |
| 1994 | 33.59 | 34.59 |
| 1995 | 34.78 | 34.59 |
| 1996 | 35.06 | 31.49 |
| 1997 | 35.42 | 27.11 |
| 1998 | 36.70 | 27.90 |
| 1999 | 38.36 | 25.41 |
| 2000 | 40.02 | 22.92 |
| 2001 | 43.58 | 31.00 |
| 2002 | 45.59 | 28.91 |
| 2003 | 46.99 | 31.66 |

Since roughly 90% of all R&D output is created in HAU, this analysis will only focus on the HAU. For this reason we use the student-to-staff ratio of these universities.

### 13.2.5 % time spent n R&D

The data from the Survey is used to find the percentage of the recorded HC spent on R&D to find the FTE. This figure is then used in the model and a regression is performed in order to model the effect the student staff relationship has on the percentage time Academic and Research staff have left to perform R&D duties.

**Table 13-9: Student-to-staff ratio and the % time spent on R&D**

| | Professional Personnel | Total HC | Amount of R&D workers (FTE) | % | HC Researchers | FTE Researchers | |
|---|---|---|---|---|---|---|---|
| 1977 | | 6425 | 2555 | 39.77% | 5053 | 1938 | 38.35% |
| 1979 | | 8181 | 3216 | 39.31% | 6406 | 2399 | 37.45% |
| 1981 | | 6116 | 2253 | 36.84% | 4044 | 1425 | 35.24% |
| 1983 | | 11465 | 4128 | 36.01% | 8841 | 3384 | 38.28% |
| 1985 | 11232 | 17889 | 6810 | 38.07% | 13588 | 5183 | 38.14% |
| 1987 | 11368 | 19943 | 6610 | 33.14% | 15417 | 5780 | 37.49% |
| 1989 | | 19682 | 6353 | 32.28% | 13978 | 5160 | 36.92% |
| 1991 | 12181 | 16514 | 6533 | 39.56% | 14540 | 5984 | 41.16% |
| 1993 | 12758 | 10835 | 4450 | 41.07% | 9916 | 4096 | 41.31% |
| 1995 | 13425 | 13425 | 4571.5 | 34.05% | 11017 | N/A | N/A |
| 1997 | 14128 | 14128 | 4693 | 33.22% | 10655 | N/A | N/A |
| 1999 | | 14128 | 4367.5 | 30.91% | 10665 | N/A | N/A |
| 2001 | 13774 | 15767 | 4042 | 25.64% | 12626 | 3425 | 27.13% |
| 2003 | 14697 | 19377 | 4553.99 | 23.50% | 14055 | 3374 | 24.01% |

As far as possible the Survey data is used for the computation of the percentage time spent on R&D. There is evidence that the definitions used in the surveys have changed, it is however still the best source of time-series data of the past 20 years.

As no data values are available for the 1995 to 1999 surveys, these values are extrapolated. By now incorporating these values, the following time series data is used for the analysis.

**Table 13-10: Constructed time series data for % time spent on R&D activities.**

| Year | HC Researchers | FTE Researchers | Percentage time spent |
|---|---|---|---|
| 1985 | 13588 | 5183 | 38.14% |
| 1987 | 15417 | 5780 | 37.49% |
| 1989 | 13978 | 5160 | 36.92% |
| 1991 | 14540 | 5984 | 41.16% |
| 1993 | 12758 | 4450 | 34.88% |
| 1995 | 13425 | 4571.5 | 34.05% |
| 1997 | 14128 | 4693 | 33.22% |
| 1999 | 13951 | 4367.5 | 31.31% |
| 2001 | 12626 | 3425 | 27.13% |
| 2003 | 14055 | 3374 | 24.01% |

## 13.3 R&D data: Public sector

### 13.3.1 R&D expenditure

**Table 13-11: R&D funding according to source**

| | Total expenditure in Sector | Source funding from HES | Funding Sourced from Private sector |
|---|---|---|---|
| 1977 | 114371000 | 236000 | 7868000 |
| 1979 | 144293000 | 137000 | 7939000 |
| 1981 | 243617580 | 10763 | 6401610 |
| 1983 | 246780000 | 215203 | 7718000 |
| 1985 | 347357000 | 168000 | 12112000 |
| 1987 | 482567000 | 232000 | 24497000 |
| 1989 | 578008000 | 322000 | 49047000 |
| 1991 | 755018000 | 0 | 77147000 |
| 1993 | 810618000 | 169000 | 109220000 |
| 1995 | N/A | N/A | N/A |
| 1997 | 1591000000 | 3000000 | 222000000 |
| 1999 | N/A | N/A | N/A |
| 2001 | 1497564000 | 0 | 241860000 |
| 2003 | 2210860000 | 2716000 | 258426000 |

**Table 13-12: R&D Expenditure in the Public sector**

| Year | R&D investment (R) | Expenditure HR | % Expenditure HR | Expenditure on Capital | % Expenditure on Capital |
|---|---|---|---|---|---|
| 1977 | 114371000 | 62625000 | 54.76% | N/A | N/A |
| 1979 | 144293000 | 50458000 | 34.97% | N/A | N/A |
| 1981 | 243617580 | 86322000 | 35.43% | 27976397 | 11.48% |
| 1983 | 246780000 | 93906000 | 38.05% | 27889000 | 11.30% |
| 1985 | 347357000 | 130664000 | 37.62% | 38792000 | 11.17% |
| 1987 | 482567000 | 188457000 | 39.05% | 43395000 | 8.99% |
| 1989 | 578008000 | 253622000 | 43.88% | 46470000 | 8.04% |
| 1991 | 755018000 | 334622000 | 44.32% | 37042000 | 4.91% |
| 1993 | 810618000 | 408281000 | 50.37% | 36393000 | 4.49% |
| 1995 | N/A | N/A | N/A | N/A | N/A |
| 1997 | 1591000000 | 731300000 | 45.96% | 65950000 | 4.15% |
| 1999 | N/A | N/A | N/A | N/A | N/A |
| 2001 | 1497564000 | 657678000 | 43.92% | 79783000 | 5.33% |
| 2003 | 2210860000 | 1088712000 | 49.24% | 183881000 | 8.32% |
| | | **Average** | 43.13% | | 7.82% |
| | | **Standard Deviation** | 6.28% | | 2.94% |

**Table 13-13: Expenditure on Human Resources by type of resources**

| | R ('000) | Researchers | % | Technicians | % | Support | |
|---|---|---|---|---|---|---|---|
| 1977 | 62625 | 25112 | 40.10% | 11653 | 18.61% | 25860 | 41.29% |
| 1979 | 50458 | 23416 | 46.41% | 15847 | 31.41% | 11195 | 22.19% |
| 1981 | 86322 | 52726 | 61.08% | 27564 | 31.93% | 6032 | 6.99% |
| 1983 | 93906 | 62134 | 66.17% | 24493 | 26.08% | 7279 | 7.75% |
| 1985 | 130664 | 85907 | 65.75% | 33154 | 25.37% | 11603 | 8.88% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1987 | 188457 | 117649 | 62.43% | 49324 | 26.17% | 21484 | 11.40% |
| 1989 | 253620 | 144231 | 56.87% | 70935 | 27.97% | 38454 | 15.16% |
| 1991 | 334622 | 184977 | 55.28% | 89964 | 26.89% | 59681 | 17.84% |
| 1993 | 408280 | 216432 | 53.01% | 111757 | 27.37% | 80091 | 19.62% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | 731300 | N/A | N/A | N/A | N/A | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 657678 | N/A | N/A | N/A | N/A | N/A | N/A |
| 2003 | 1088712 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Average** | | | 56.34% | | 26.87% | | 16.79% |
| **Standard Deviation** | | | 8.80% | | 3.86% | | 10.67% |

**Table 13-14: Investment in Research by type**

| | Total | Basic | % | Applied | % | Development | % |
|---|---|---|---|---|---|---|---|
| 1979 | 144293 | 16674 | 11.56% | 85867 | 59.51% | 41752 | 28.94% |
| 1981 | 243617.6 | 28796 | 11.82% | 115703 | 47.49% | 69493 | 28.53% |
| 1983 | 234779 | 39637 | 16.88% | 133451 | 56.84% | 61689 | 26.28% |
| 1985 | 347357 | 50164 | 14.44% | 188689 | 54.32% | 108505 | 31.24% |
| 1987 | 482567 | 107057 | 22.18% | 252188 | 52.26% | 123322 | 25.56% |
| 1989 | 578008 | 80323 | 13.90% | 367204 | 63.53% | 130481 | 22.57% |
| 1991 | 755018 | 98081 | 12.99% | 384481 | 50.92% | 269966 | 35.76% |
| 1993 | 810618 | 82414 | 10.17% | 464640 | 57.32% | 263564 | 32.51% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 1497564 | 432260 | 28.86% | 704864 | 47.07% | 360109 | 24.05% |
| 2003 | 2210860 | 694769 | 31.43% | 1036447 | 46.88% | 479644 | 21.69% |
| **Average** | | | 17.42% | | 53.61% | | 27.71% |
| **Standard Deviation** | | | 7.52% | | 5.70% | | 4.54% |

## 13.3.2 Human Resources

**Table 13-15: Recorded HC Research personnel in Frascati R&D Surveys**

| | total HC | HC Researchers | % | HC Tech | % | HD Support | % |
|---|---|---|---|---|---|---|---|
| 1977 | 10202 | 2709 | 26.55% | 2008 | 19.68% | 5485 | 53.76% |
| 1979 | 9268 | 2596 | 28.01% | 2784 | 30.04% | 3888 | 41.95% |
| 1981 | 7355 | 3703 | 50.35% | 2294 | 31.19% | 1358 | 18.46% |
| 1983 | 5764 | 3029 | 52.55% | 1763 | 30.59% | 972 | 16.86% |
| 1985 | 7306 | 3739 | 51.18% | 2049 | 28.05% | 1518 | 20.78% |
| 1987 | 8990 | 5114 | 56.89% | 2030 | 22.58% | 1846 | 20.53% |
| 1989 | 8854 | 3564 | 40.25% | 2791 | 31.52% | 2499 | 28.22% |
| 1991 | 8419 | 3116 | 37.01% | 2129 | 25.29% | 3174 | 37.70% |
| 1993 | 8854 | 3113 | 35.16% | 2392 | 27.02% | 3348 | 37.81% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 8012 | 2774 | 34.62% | 1762 | 21.99% | 3476 | 43.38% |
| 2003 | 8805 | 3343 | 37.97% | 1934 | 21.96% | 3528 | 40.07% |
| **Average** | | | **41.26%** | | **26.79%** | | **31.95%** |
| **Standard Deviation** | | | **10.77%** | | **4.24%** | | **12.70%** |

**Table 13-16: Recorded FTE Research personnel in Frascati R&D Surveys**

| | Total FTE | Researchers | % | Technical personnel | % | Support personnel | % |
|---|---|---|---|---|---|---|---|
| 1977 | 8512 | 2222 | 26.10% | 1721 | 20.22% | 4569 | 53.68% |
| 1979 | 7678 | 2095 | 27.29% | 2195 | 28.59% | 3388 | 44.13% |
| 1981 | 5563 | 2601 | 46.76% | 2015 | 36.22% | 947 | 17.02% |
| 1983 | 4848 | 2457 | 50.68% | 1564 | 32.26% | 827 | 17.06% |
| 1985 | 5216 | 2510 | 48.12% | 1692 | 32.44% | 1014 | 19.44% |
| 1987 | 6374 | 3173 | 49.78% | 1896 | 29.75% | 1305 | 20.47% |
| 1989 | 6426 | 2547 | 39.64% | 2209 | 34.38% | 1670 | 25.99% |
| 1991 | 6654 | 2419 | 36.35% | 1810 | 27.20% | 2425 | 36.44% |
| 1993 | 7060 | 2303 | 32.62% | 1923 | 27.24% | 2834 | 40.14% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | 6400 | 2295 | 35.86% | 1749 | 27.33% | 2356 | 36.81% |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 5171 | 2134 | 41.27% | 1195 | 23.11% | 1842 | 35.62% |
| 2003 | 5389 | 1900 | 35.25% | 1304 | 24.19% | 2186 | 40.56% |
| | | **Average** | **39.14%** | | **28.58%** | | **32.28%** |
| | | **Standard Deviation** | **8.40%** | | **4.73%** | | **12.01%** |

For 2003, only the Science Council data is included – not available for other organisations in the Government sector

**Table 13-17: Human Resources breakdown analysis on the Public sector**

| | Total HC | HC Researchers | Total FTE | FTE Researchers | % All staff | % Researchers |
|---|---|---|---|---|---|---|
| 1977 | 10202 | 2709 | 8512 | 2222 | 83.43% | 82.02% |
| 1979 | 9268 | 2596 | 7678 | 2095 | 82.84% | 80.70% |
| 1981 | 7355 | 3703 | 5563 | 2601 | 75.64% | 70.24% |
| 1983 | 5764 | 3029 | 4848 | 2457 | 84.11% | 81.12% |
| 1985 | 7306 | 3739 | 5216 | 2510 | 71.39% | 67.13% |
| 1987 | 8990 | 5114 | 6374 | 3173 | 70.90% | 62.05% |
| 1989 | 8854 | 3564 | 6426 | 2547 | 72.58% | 71.46% |
| 1991 | 8419 | 3116 | 6654 | 2419 | 79.04% | 77.63% |
| 1993 | 8854 | 3113 | 7060 | 2303 | 79.74% | 73.98% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | N/A | N/A | 6400 | 2295 | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 8012 | 2774 | 5171 | 2134 | 64.54% | 76.93% |
| 2003 | 8805 | 3343 | 5389.41 | 2503 | 61.21% | 74.87% |
| | | | | | 75.04% | 74.38% |
| | | | | | 7.68% | 6.26% |

**Table 13-18: Human Resources time spent on R&D analysis**

| | total HC | Total FTE | % time spent | HC Researchers | FTE Researchers | % time spent |
|---|---|---|---|---|---|---|
| 1977 | 10202 | 8512 | 83.43% | 2709 | 2222 | 82.02% |
| 1979 | 9268 | 7678 | 82.84% | 2596 | 2095 | 80.70% |
| 1981 | 7355 | 5563 | 75.64% | 3703 | 2601 | 70.24% |
| 1983 | 5764 | 4848 | 84.11% | 3029 | 2457 | 81.12% |
| 1985 | 7306 | 5216 | 71.39% | 3739 | 2510 | 67.13% |
| 1987 | 8990 | 6374 | 70.90% | 5114 | 3173 | 62.05% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1989 | 8854 | 6426 | 72.58% | 3564 | 2547 | 71.46% |
| 1991 | 8419 | 6654 | 79.04% | 3116 | 2419 | 77.63% |
| 1993 | 8854 | 7060 | 79.74% | 3113 | 2303 | 73.98% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | N/A | 6400 | N/A | N/A | 2295 | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 8012 | 5171 | 64.54% | 2774 | 2134 | 76.93% |
| 2003 | 8805 | 5389 | 61.21% | 3343 | 2503 | 74.87% |
| **Average** | | | 75.04% | | | 74.38% |
| **Standard Deviation** | | | 7.68% | | | 6.26% |

## 13.4 R&D Data: Private sector

### 13.4.1 R&D investment

**Table 13-19: R&D expenditure by sources of funding in the Private sector**

| | Total expenditure in Sector | Source funding from HES | % funding from HES | Funding Sourced from Pub | % funding from Public sector |
|---|---|---|---|---|---|
| 1977 | 68141000 | 0 | 0.00% | 3443000 | 5.05% |
| 1979 | 100594000 | 0 | 0.00% | 2625000 | 2.61% |
| 1981 | 185180000 | 0 | 0.00% | 2989340 | 1.61% |
| 1983 | 378550100 | 55813 | 0.01% | 1846236 | 0.49% |
| 1985 | 413462000 | 61000 | 0.01% | 3185000 | 0.77% |
| 1987 | 495836000 | 74000 | 0.01% | 3333000 | 0.67% |
| 1989 | 656951000 | 0 | 0.00% | 13257000 | 2.02% |
| 1991 | 1297602000 | 709000 | 0.05% | 133766000 | 10.31% |
| 1993 | 1336227000 | 828000 | 0.06% | 60861000 | 4.55% |
| 1995 | N/A | N/A | N/A | N/A | N/A |
| 1997 | 2216000000 | 1000000 | 0.05% | 186000000 | 8.39% |
| 1999 | N/A | N/A | N/A | N/A | N/A |
| 2001 | 4023576000 | 0 | 0.00% | 392614000 | 9.76% |
| 2003 | 5591325000 | 5133000 | 0.09% | 354504000 | 6.34% |
| | | **Average** | 0.02% | | 4.38% |
| | | **Standard Deviation** | 0.03% | | 3.60% |

**Table 13-20: R&D Expenditure in the Private sector**

| | Total expenditure in Sector | Salary HR | % HR | Spending on Capital | % Capital |
|---|---|---|---|---|---|
| 1977 | 68141000 | 36628000 | 53.75% | 9287000 | 13.63% |
| 1979 | 100594000 | 43916000 | 43.66% | N/A | N/A |
| 1981 | 185180000 | 91956000 | 49.66% | 33250000 | 17.96% |
| 1983 | 378550100 | 165828000 | 43.81% | 43816000 | 11.57% |
| 1985 | 413462000 | 212679000 | 51.44% | 32751000 | 7.92% |
| 1987 | 495836000 | 258214000 | 52.08% | 60277000 | 12.16% |
| 1989 | 656951000 | 302719000 | 46.08% | 70283000 | 10.70% |
| 1991 | 1297602000 | 703578000 | 54.22% | 171137000 | 13.19% |
| 1993 | 1336227000 | 682289000 | 51.06% | 135991000 | 10.18% |
| 1995 | N/A | N/A | N/A | N/A | N/A |
| 1997 | 2216000000 | 1294600000 | 58.42% | 627000000 | 2.83% |
| 1999 | N/A | N/A | N/A | N/A | N/A |
| 2001 | 4023576000 | 1718373000 | 42.71% | 782323000 | 19.44% |
| 2003 | 5591325000 | 2488458000 | 44.51% | 775849000 | 13.88% |
| | | **Average** | **49.28%** | | **14.35%** |
| | | **Standard Deviation** | **5.06%** | | **9.88%** |

**Table 13-21: R&D expenditure by type of R&D in the Private sector**

| | Total | Basic | % | Applied | % | Development | % |
|---|---|---|---|---|---|---|---|
| 1979 | 100594 | 4948 | 4.92% | 35668 | 35.46% | 59978 | 59.62% |
| 1981 | 185178 | 3164 | 1.71% | 44650 | 24.11% | 137364 | 74.18% |
| 1983 | 378550 | 9437 | 2.49% | 94560 | 24.98% | 274553 | 72.53% |
| 1985 | 413462 | 28053 | 6.78% | 135383 | 32.74% | 250026 | 60.47% |
| 1987 | 495837 | 34664 | 6.99% | 224048 | 45.19% | 237125 | 47.82% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1989 | 656950 | 32645 | 4.97% | 266940 | 40.63% | 357365 | 54.40% |
| 1991 | 1297622 | 68633 | 5.29% | 514449 | 39.65% | 714540 | 55.07% |
| 1993 | 1336227 | 22617 | 1.69% | 406738 | 30.44% | 906872 | 67.87% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | 2215900 | 225200 | 10.16% | 668800 | 30.18% | 1322000 | 59.66% |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 3736605 | 663819 | 17.77% | 1397968 | 37.41% | 1674818 | 44.82% |
| 2003 | 5591325 | 759345 | 13.58% | 1883082 | 33.68% | 2948898 | 52.74% |
| **Average** | | | 6.62% | | 34.43% | | 58.95% |
| **Standard Deviation** | | | 5.22% | | 6.72% | | 9.98% |

## 13.4.2 Human Resources

**Table 13-22: Human Resources Headcount employed in the Business sector**

| | total HC | HC Researchers | % | HC Tech | % | HD Support | % |
|---|---|---|---|---|---|---|---|
| 1977 | 6569 | 1790 | 27.25% | 1742 | 26.52% | 3037 | 46.23% |
| 1979 | 6091 | 2180 | 35.79% | 1685 | 27.66% | 2226 | 36.55% |
| 1981 | 7185 | 2403 | 33.44% | 2098 | 29.20% | 2694 | 37.49% |
| 1983 | 8834 | 2676 | 30.29% | 3203 | 36.26% | 2955 | 33.45% |
| 1985 | 9565 | 2744 | 28.69% | 4040 | 42.24% | 2781 | 29.07% |
| 1987 | 9828 | 3000 | 30.53% | 4005 | 40.75% | 2823 | 28.72% |
| 1989 | 7446 | 2396 | 32.18% | 1960 | 26.32% | 3090 | 41.50% |
| 1991 | 11791 | 4688 | 39.76% | 3444 | 29.21% | 3659 | 31.03% |
| 1993 | 9768 | 5157 | 52.79% | 2585 | 26.46% | 2026 | 20.74% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | 8111 | 4113 | 50.71% | 2208 | 27.22% | 1790 | 22.07% |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 8284 | 3753 | 45.30% | 2488 | 30.03% | 2043 | 24.66% |
| 2003 | 11608 | 5058 | 43.57% | 3430 | 29.55% | 3120 | 26.88% |
| Average | | | 37.53% | | 30.95% | | 31.53% |
| Standard Deviation | | | 8.75% | | 5.61% | | 7.80% |

**Table 13-23: FTE Human Resources employed in the Business sector**

| | Total FTE | Researchers | % | Technical personnel | % | Support personnel | % |
|---|---|---|---|---|---|---|---|
| 1977 | 4237 | 1375 | 32.45% | 1342 | 31.67% | 1520 | 35.87% |
| 1979 | 4088 | 1380 | 33.76% | 1207 | 29.53% | 1501 | 36.72% |
| 1981 | 5494 | 1937 | 35.26% | 1738 | 31.63% | 1819 | 33.11% |
| 1983 | 6771 | 1990 | 29.39% | 2646 | 39.08% | 2135 | 31.53% |
| 1985 | 7196 | 2130 | 29.60% | 3328 | 46.25% | 1738 | 24.15% |
| 1987 | 7257 | 2372 | 32.69% | 3132 | 43.16% | 1753 | 24.16% |
| 1989 | 5008 | 2001 | 39.96% | 1431 | 28.57% | 1576 | 31.47% |
| 1991 | 8481 | 3396 | 40.04% | 2785 | 32.84% | 2300 | 27.12% |
| 1993 | 7649 | 4341 | 56.75% | 1869 | 24.43% | 1439 | 18.81% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 6209 | 2952 | 47.54% | 1916 | 30.86% | 1341 | 21.60% |
| 2003 | 9132 | 4153 | 45.48% | 2605 | 28.53% | 2374 | 26.00% |
| **Average** | | | 38.45% | | 33.32% | | 28.23% |
| **Standard Deviation** | | | 8.57% | | 6.69% | | 5.90% |

**Table 13-24: Research staff data in the Business sector**

| | HC (all) | FTE (All) | | HC (Researchers) | FTE (Researchers) | |
|---|---|---|---|---|---|---|
| 1977 | 6569 | 4237 | 64.50% | 1790 | 1375 | 76.82% |
| 1979 | 6091 | 4088 | 67.12% | 2180 | 1380 | 63.30% |
| 1981 | 7185 | 5494 | 76.46% | 2403 | 1937 | 80.61% |
| 1983 | 8834 | 6771 | 76.65% | 2676 | 1990 | 74.36% |
| 1985 | 9565 | 7196 | 75.23% | 2744 | 2130 | 77.62% |
| 1987 | 9828 | 7257 | 73.84% | 3000 | 2372 | 79.07% |
| 1989 | 7446 | 5008 | 67.26% | 2396 | 2001 | 83.51% |
| 1991 | 11791 | 8481 | 71.93% | 4688 | 3396 | 72.44% |
| 1993 | 9768 | 7649 | 78.31% | 5157 | 4341 | 84.18% |
| 1995 | N/A | N/A | N/A | N/A | N/A | N/A |
| 1997 | 8111 | N/A | N/A | 4113 | N/A | N/A |
| 1999 | N/A | N/A | N/A | N/A | N/A | N/A |
| 2001 | 8284 | 6209 | 74.95% | 3753 | 2952 | 78.66% |
| 2003 | 11608 | 9132 | 78.67% | 5058 | 4153 | 82.11% |
| | | **Average** | 73.17% | | | 77.52% |
| | | **Standard Deviation** | 4.86% | | | 5.94% |

## 13.5 The time value of money.

Inflation causes a currency's actual value to depreciate. In order to be able to make a meaningful comparison over the years regarding R&D investment and expenditure, it makes sense to look at it in terms of a constant Rand value. The consumer price index (StatsSA, 2005) was used to find the factor each year has to be multiplied with to find the 2001 Rand value. If one wants to express amount y from year Y in terms of Rand value in year x the following formula is used:

$$Factor = \frac{Index_{yearX}}{Index_{yearY}} \qquad \textbf{13-1}$$

**Table 13-25: Time value of money computed from consumer price index (StatsSA, 2005)**

| Year | Index | Factor for 2001 Rand |
|---|---|---|
| 1977 | 7.6 | 13.90789 |
| 1978 | 8.4 | 12.58333 |
| 1979 | 9.5 | 11.12632 |
| 1980 | 10.8 | 9.787037 |
| 1981 | 12.5 | 8.456 |
| 1982 | 14.3 | 7.391608 |
| 1983 | 16.1 | 6.565217 |
| 1984 | 17.9 | 5.905028 |
| 1985 | 20.8 | 5.081731 |
| 1986 | 24.7 | 4.279352 |
| 1987 | 28.7 | 3.682927 |
| 1988 | 32.4 | 3.262346 |
| 1989 | 37.1 | 2.849057 |
| 1990 | 42.4 | 2.492925 |
| 1991 | 49.0 | 2.157143 |
| 1992 | 55.7 | 1.897666 |
| 1993 | 61.2 | 1.727124 |
| 1994 | 66.6 | 1.587087 |
| 1995 | 72.4 | 1.459945 |

| | | |
|---|---|---|
| 1996 | 77.7 | 1.36036 |
| 1997 | 84.4 | 1.25237 |
| 1998 | 90.2 | 1.17184 |
| 1999 | 94.9 | 1.113804 |
| 2000 | 100.0 | 1.057 |
| 2001 | 105.7 | 1 |

# 14 APPENDIX C

## 14.1 Absorption of Knowledge (HES)

The rate at which the system is able to produce new knowledge output is computed through the contribution made form different stocks in the system. The following expression is formulated for the R&D knowledge absorption rate in the system:

- $R_{Absorptionr}$ : Absorption rate of knowledge in the system
- $S_{R\&Doutput} * S_{FTE}$: RD output stock interacting with the presence of full time equivalent people who can draw on the stocks of knowledge in system
- $S_{World} / S_{HC}$: Available external knowledge stock per Headcount personnel employed in the system

A multiplicative model is developed for the absorption rate per full time person working in the system:

$$\frac{R_{Absorptionr}}{R^*_{Absorption}} = f * (\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}})^d * (\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}})^e \qquad \textbf{14-1}$$

This expression is linearised by taking the log-linear form:

$$\ln(\frac{R_{Absorptionr}}{R^*_{Absorption}}) = f + d * \ln(\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}}) + e * \ln(\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}})$$

**14-2**

This is the expression used to perform the regression for estimating the parameters $d$ , $e$ and $f$ .

The section describes the variables included in the model to estimate the rate of knowledge absorption in the system. The following SAS program was used.

**Table 14-1: SAS code for stationarity tests in variables AbsorbedR, rdfte and wsperhc**

```
goptions reset=all cback=white colors=(black) lfactor=2
border;
title1 'Trend Plot';
proc gplotb data = HES.hesloglin;
plot (AbsorbedR rdfte wsperhc)*year;
plot AbsorbedR *(rdfte wsperhc);
run;

* test for stationarity of the 3 series using arima procedure
*;
proc arima data=hes.loglin;
identify var= AbsorbedR stationarity=(phillips=(0,1));
identify var=rdfte stationarity=(phillips=(0,1));
```

```
identify var=wsperhc stationarity=(phillips=(0,1));
                                 run;
```

The following sections document and explain the output obtained from the SAS program.

### 14.1.1 Absorption rate of knowledge in the system

The following is the time plot output from the SAS program for the absorption rate per full time equivalent researchers in the system.

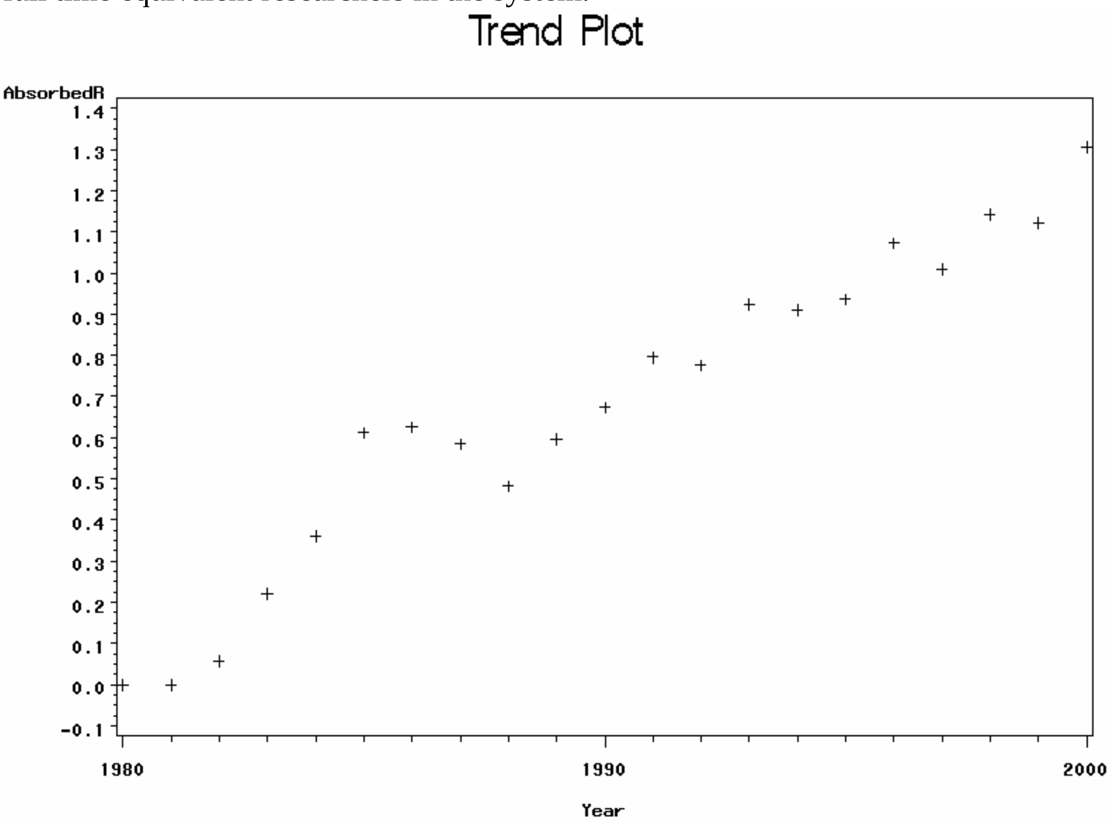


**Figure 14-1 Time plot of the absorption rate in the Higher Education system**

From Figure 14-1 can be seen that the time plot shows an upward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 14-2: Phillips-Perron test output for variable "AbsorbedR"**

```
                        The ARIMA Procedure

                    Name of Variable = AbsorbedR

                 Mean of Working Series    0.707911
                 Standard Deviation        0.393853
                 Number of Observations          22

                   Phillips-Perron Unit Root Tests

Type              Lags          Rho    Pr < Rho         Tau    Pr < Tau

Zero Mean            0       1.3497      0.9411        2.23      0.9912
                     1       1.3478      0.9409        2.21      0.9909
```

| | | | | | |
|---|---|---|---|---|---|
| Single Mean | 0 | -0.8467 | 0.8869 | -0.74 | 0.8157 |
| | 1 | -0.7612 | 0.8944 | -0.71 | 0.8224 |
| Trend | 0 | -10.2431 | 0.3187 | -2.46 | 0.3408 |
| | 1 | -10.4180 | 0.3065 | -2.48 | 0.3337 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

Pr < Tau = 0.3408 for $\ell = 0$ en

Pr < Tau = 0.3337 for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that AbsorbedR has a unit root and is non-stationary.

### 14.1.2 R&D Knowledge Stock and FTE researchers

The following is the time plot output from the SAS program for the interaction of Full time equivalent personnel in the system with the R&D Knowledge stock.

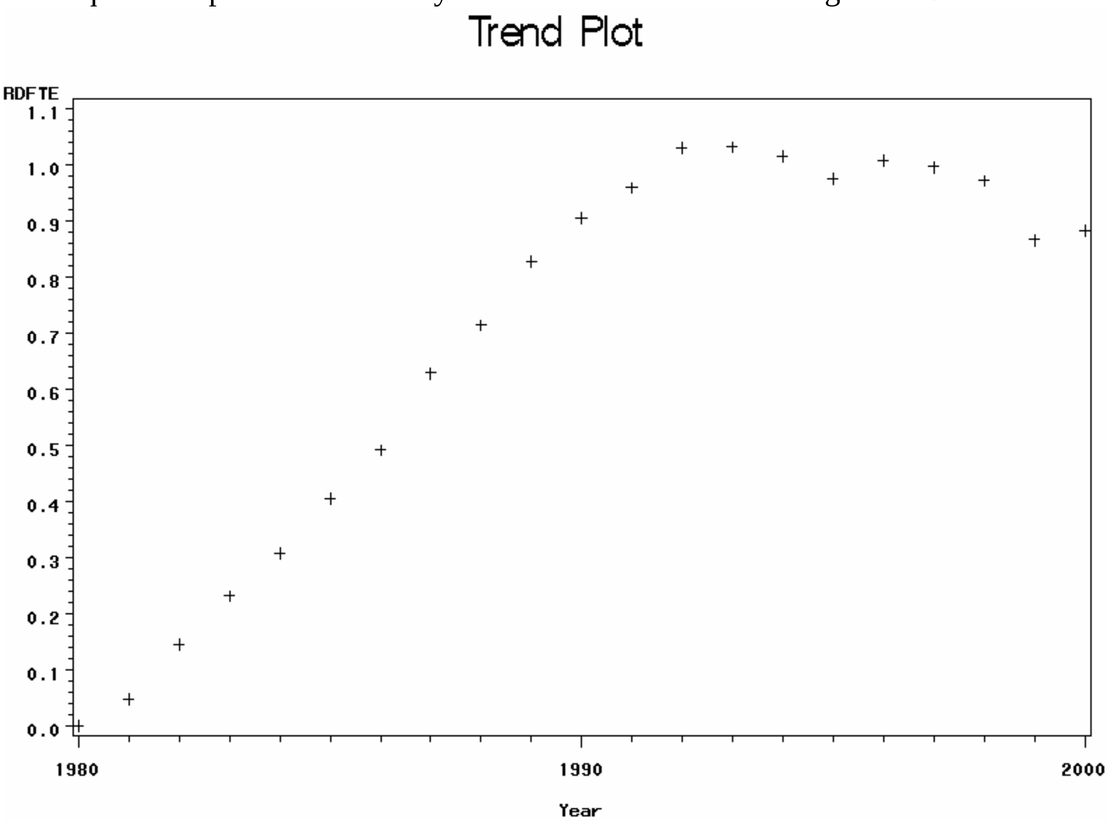


**Figure 14-2 Time plot - FTE researcher interacting with R&D knowledge**

From Figure 14-2 can be seen that the time plot shows an upward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 14-3: Phillips-Perron test output for variable "RDFTE"**

```
The ARIMA Procedure
```

```
                    Name of Variable = RDFTE

               Mean of Working Series    0.701877
               Standard Deviation        0.347422
               Number of Observations          22

               Phillips-Perron Unit Root Tests

Type           Lags         Rho    Pr < Rho       Tau    Pr < Tau

Zero Mean         0      0.7167      0.8424      1.65      0.9717
                  1      0.6539      0.8288      1.15      0.9302
Single Mean       0     -2.0640      0.7546     -3.08      0.0438
                  1     -2.1431      0.7448     -2.72      0.0876
Trend             0     -0.7058      0.9868     -0.49      0.9750
                  1     -0.9342      0.9839     -0.59      0.9684
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.9750` for $\ell$ = 0 en

`Pr < Tau = 0.9684` for $\ell$ = 1.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `RDFTE` has a unit root and is non-stationary.

### 14.1.3 The World knowledge stock

The following is the time plot output from the SAS program for the World Knowledge Stock per Headcount person employed in the Higher Education system.

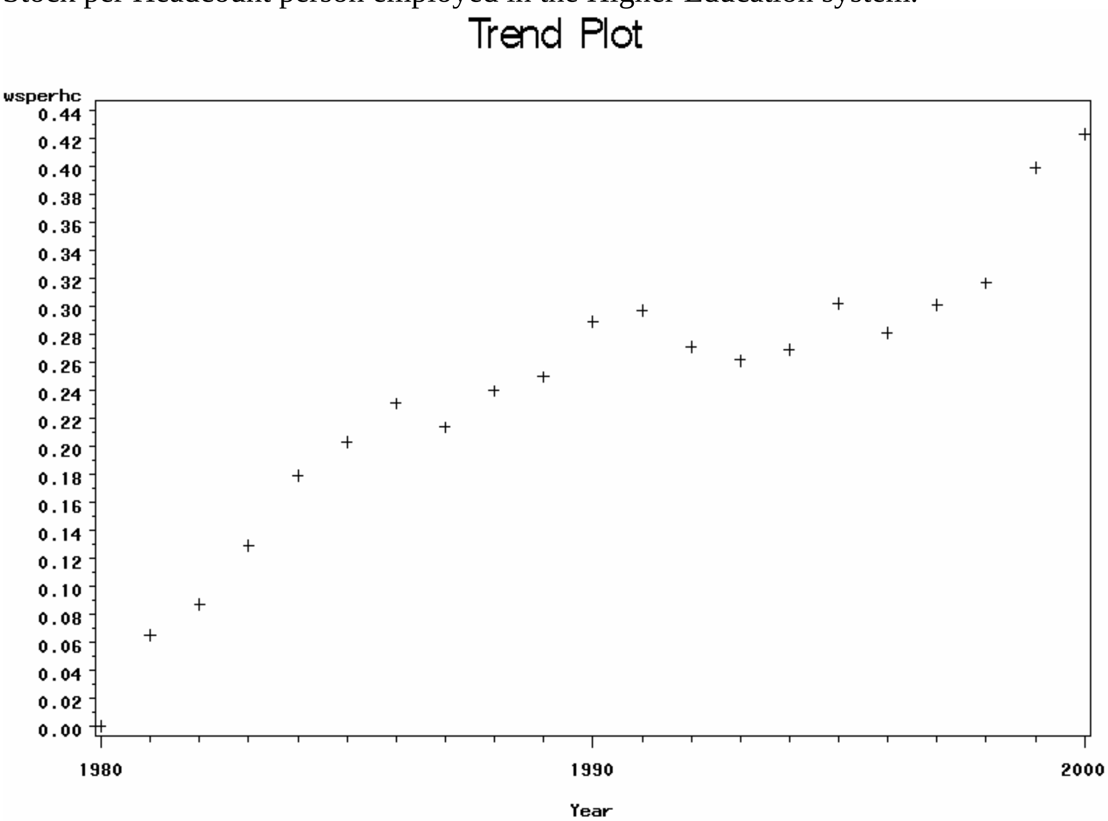


**Figure 14-3 Time plot of the World stock of knowledge per HC researcher**

From Figure 14-3 can be seen that the time plot shows an upward trend line. We therefore make use of the “Trend” specification in the stationarity test output results.

**Table 14-4: Phillips-Perron test output for variable “wsperhc”**

```
                           The ARIMA Procedure

                        Name of Variable = wsperhc

                    Mean of Working Series    0.247072
                    Standard Deviation        0.105268
                    Number of Observations          22

                     Phillips-Perron Unit Root Tests

      Type            Lags          Rho     Pr < Rho        Tau     Pr < Tau

      Zero Mean          0       1.1493       0.9175       2.10       0.9884
                         1       1.1216       0.9137       1.87       0.9815
      Single Mean        0      -2.3311       0.7210      -2.00       0.2838
                         1      -2.4006       0.7122      -1.96       0.3021
      Trend              0      -7.5941       0.5431      -2.70       0.2457
                         1      -8.1564       0.4906      -2.70       0.2456
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.2457` for $\ell = 0$ en

`Pr < Tau = 0.2456` for $\ell = 1$.

Both $p$-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `wsperhc` has a unit root and is non-stationary.

### 14.1.4 Colinearity tests

First however we should make sure that the variables are not collinear. The following is the test results obtained from SAS for the Colinearity test.

**Table 14-5: Colinearity diagnostics for the model variables**

```
                          Collinearity Diagnostics

                                                   Condition
                     Number      Eigenvalue           Index

                          1         2.86046         1.00000
                          2         0.11563         4.97380
                          3         0.02392        10.93637

                          Collinearity Diagnostics

                        ---------Proportion of Variation---------
             Number       Intercept           RDFTE         wsperhc

                  1         0.01733         0.00605         0.00480
                  2         0.87833         0.11364         0.02912
                  3         0.10434         0.88032         0.96608
```

Larger values suggest potential near colinearity. Belsley, Kuh and Welsch (2000) recommend interpreting the Condition index greater or equal than 30 to reflect moderate to severe colinearity, worthy of further investigation. Since all the Condition indexes from the regression model are much smaller than 30, the conclusion can be made that colinearity is not a problem in this case.

***Proportion of Variation***

The variance proportion indicates for each predictor the proportion of total variance of its estimated regression coefficients associated with a particular principal component. The variance proportions suggest colinearity problems if more than one predictor has high variance proportions of at least 0.5, such a component suggest a problem. One should definitely be concerned when two or more ladings greater than 0.9 appear on a component with a large condition index (>30). This also does not seem to be a problem since the condition indexes are all smaller than 30.

### 14.1.5 Model estimation - Absorption rate (HES)

As all three variables are non-stationary, we should now fit a model and then test for co-integration in the residual to prove that the modelled relationship is non-spurious.

**Table 14-6: SAS code for the model estimation procedure**

```
proc autoreg data= HES.hesloglin;
model absorbedR = rdFTE wsperhc
/ method= ml nlag=1 dwprob;
output out=b r=residual;
run;
```

**Table 14-7: SAS output for the model estimation of Absorptive capacity in the HES**

```
                          The AUTOREG Procedure

                       Dependent Variable    AbsorbedR

                       Ordinary Least Squares Estimates

     SSE                     0.27533496    DFE                       19
     MSE                        0.01449    Root MSE             0.12038
     SBC                     -24.671383    AIC                -27.94451
     Regress R-Square            0.9193    Total R-Square          0.9193
     Durbin-Watson               1.0282    Pr < DW                 0.0014
     Pr > DW                     0.9986
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and
      Pr>DW is the p-value for testing negative autocorrelation.

                              Phillips-Ouliaris
                             Cointegration Test

                       Lags            Rho            Tau

                          1       -11.8653       -2.9582

                                           Standard                 Approx
```

| Variable | DF | Estimate | Error | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | -0.1717 | 0.0655 | -2.62 | 0.0167 |
| RDFTE | 1 | 0.2663 | 0.1444 | 1.84 | 0.0809 |
| wsperhc | 1 | 2.8038 | 0.4767 | 5.88 | <.0001 |

Q and LM Tests for ARCH Disturbances

| Order | Q | Pr > Q | LM | Pr > LM |
|---|---|---|---|---|
| 1 | 0.1107 | 0.7393 | 0.0064 | 0.9360 |
| 2 | 1.0439 | 0.5934 | 0.6325 | 0.7289 |
| 3 | 2.1377 | 0.5443 | 1.4751 | 0.6880 |
| 4 | 5.2369 | 0.2638 | 3.5521 | 0.4700 |
| 5 | 6.1404 | 0.2928 | 3.5763 | 0.6119 |
| 6 | 6.3389 | 0.3863 | 3.8539 | 0.6964 |
| 7 | 8.5847 | 0.2839 | 4.9011 | 0.6720 |
| 8 | 13.1218 | 0.1077 | 11.4069 | 0.1797 |
| 9 | 13.8131 | 0.1291 | 13.0194 | 0.1617 |
| 10 | 14.6261 | 0.1463 | 13.0194 | 0.2226 |
| 11 | 14.7742 | 0.1931 | 13.0199 | 0.2920 |
| 12 | 15.2048 | 0.2304 | 13.0824 | 0.3631 |

Maximum Likelihood Estimates

| | | | |
|---|---|---|---|
| SSE | 0.18500614 | DFE | 18 |
| MSE | 0.01028 | Root MSE | 0.10138 |
| SBC | -29.491802 | AIC | -33.855972 |
| Regress R-Square | 0.6812 | Total R-Square | 0.9458 |
| Durbin-Watson | 2.0372 | Pr < DW | 0.4148 |
| Pr > DW | 0.5852 | | |

NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value for testing negative autocorrelation.

| Variable | DF | Estimate | Standard Error | t Value | Approx Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | -0.0443 | 0.1432 | -0.31 | 0.7606 |
| RDFTE | 1 | 0.6165 | 0.2642 | 2.33 | 0.0314 |
| wsperhc | 1 | 1.4308 | 0.6667 | 2.15 | 0.0457 |
| AR1 | 1 | -0.7526 | 0.1944 | -3.87 | 0.0011 |

Autoregressive parameters assumed given.

| Variable | DF | Estimate | Standard Error | t Value | Approx Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | -0.0443 | 0.1431 | -0.31 | 0.7606 |
| RDFTE | 1 | 0.6165 | 0.2303 | 2.68 | 0.0154 |
| wsperhc | 1 | 1.4308 | 0.6188 | 2.31 | 0.0328 |

From the model estimation output obtained we can make the following conclusion:

The test for autocorrelation use is the Durban Watson test statistic. The `Durbin Watson` test statistic is 2.0372 with (Pr < DW = 0.4148) > 0.05 and (Pr < DW = 0.5852) < 0.95. This indicates that we can we therefore can conclude that the model does not have autocorrelation.

Due to the small sample size and the limited number of data points available, the heteroscedasticity test (Q and LM test for ARCH disturbances) is only interpreted up to 2 time lags. The probability for arch disturbances in the model for lags 1 and 2 are larger than 0.05. We can therefore conclude that the modelled relationship does not suffer from heteroscedasticity.

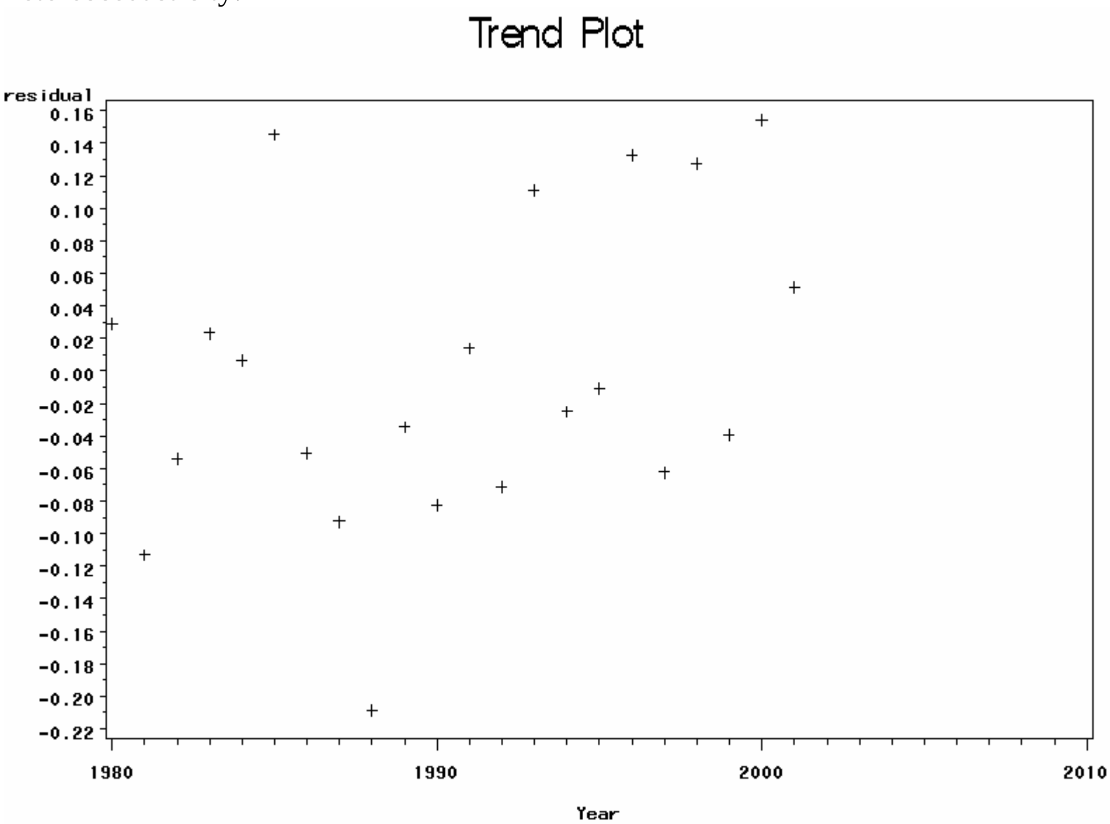


**Figure 14-4: Time plot for the residual of the HES knowledge absorption**

From Table 14-4 can be seen that the time plot seems to be scattered around 0. From the results we van also read the Mean of Working Series -0.00219. We therefore make use of the “Zero mean” specification in the stationarity test output results.

**Table 14-8: Phillips Perron tests output for the residual**

The ARIMA Procedure

Name of Variable = residual

| | |
|---|---|
| Mean of Working Series | -0.00219 |
| Standard Deviation | 0.091676 |
| Number of Observations | 22 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -21.4679 | 0.0001 | -4.55 | 0.0001 |
| | 1 | -21.7305 | <.0001 | -4.55 | 0.0001 |
| Single Mean | 0 | -21.5116 | 0.0008 | -4.44 | 0.0023 |
| | 1 | -21.7978 | 0.0007 | -4.44 | 0.0023 |
| Trend | 0 | -24.5472 | 0.0018 | -5.17 | 0.0024 |
| | 1 | -25.2333 | 0.0012 | -5.15 | 0.0026 |

Since an intercept is included in the model fitted, an intercept is included. For (n-1) = 2, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See **Error! Reference source not found.**). The critical value for the 1% level is -4.31.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Tau = -4.55` for $\ell = 0$ en

`Tau = -4.55` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

## 14.2 Creation of new knowledge (HES)

The rate at which the system is able to produce new knowledge output is computed through the contribution made form different stocks in the system. The following expression is formulated for the R&D output productivity per FTE researcher working in the system:

- $R_{Paper} / S_{FTE}$ : R&D output rate per FTE researcher person on the system
- $S_{Experience} / S_{HC}$ : Average Experience Stock of the people in the system.
- $S_{Absorbed} / S_{HC}$ : Average Absorbed knowledge per person in the system.

A multiplicative model is developed for the development rate of papers per full time person working in the system:

$$\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}} = c * (\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}})^a * (\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}})^b \quad \textbf{14-3}$$

This expression is linearised by taking the log-linear form:

$$\ln(\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}}) = \ln(c) + a * \ln(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}) + b * \ln(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}) \quad \textbf{14-4}$$

This is then the expression used to perform the regression for estimating the parameters $a$, $b$ and $c$.

The section describes the variables included in the model to estimate the rate of knowledge creation in the system. The following SAS program was used:

**Table 14-9: SAS code for stationarity tests in variables prperfte, expperhc and absperhc**

```
goptions reset=all cback=white colors=(black) lfactor=2
border;
title1 'Trend Plot';
proc gplot hes.rdloglin;
plot (prperfte expperhc absperhc)*year;
plot prperfte*(expperhc absperhc);
run;

* test for stationarity of the 3 series using arima procedure
*;
proc arima hes.rdloglin;
identify var=prperfte stationarity=(phillips=(0,1));
identify var=expperhc stationarity=(phillips=(0,1));
identify var=absperhc stationarity=(phillips=(0,1));
run;
```

The following sections document and explain the output obtained from the SAS program.

### 14.2.1 R&D output produced per FTE researcher

The following is the time plot output from the SAS program for the R&D output (papers) created per full time equivalent researcher in the system.

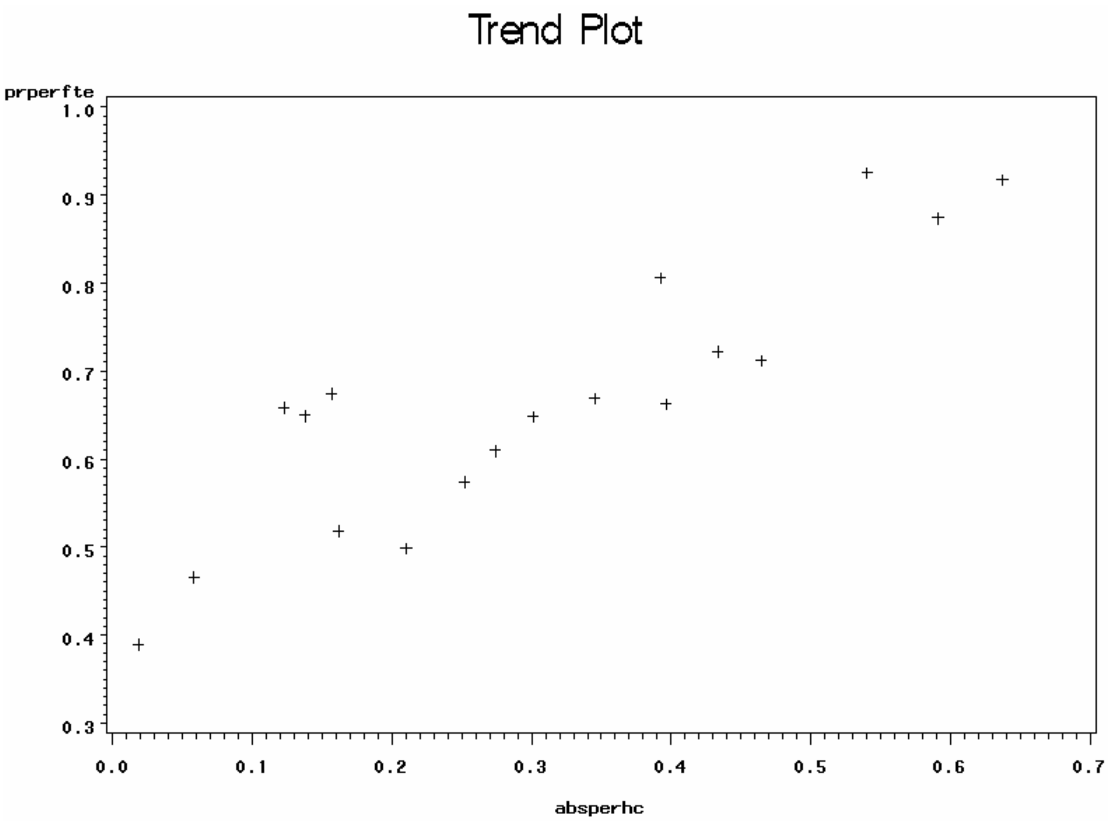


**Figure 14-5 Time plot of the Knowledge creation rate per FTE**

From Figure 14-5 can be seen that the time plot shows an upward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 14-10: SAS output for Phillips Perron test for variable "prperfte"**

```
                    The ARIMA Procedure

                 Name of Variable = prperfte

              Mean of Working Series    0.669785
              Standard Deviation        0.163311
              Number of Observations          19

                 Phillips-Perron Unit Root Tests

Type           Lags       Rho    Pr < Rho      Tau    Pr < Tau

Zero Mean         0     0.6424     0.8229     0.99      0.9068
                  1     0.6918     0.8338     1.23      0.9372
Single Mean       0    -4.7059     0.4187    -1.83      0.3549
                  1    -4.1852     0.4788    -1.78      0.3767
Trend             0   -12.4121     0.1682    -3.03      0.1527
                  1   -12.2779     0.1749    -3.02      0.1543
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.1527` for $\ell = 0$ en

`Pr < Tau = 0.1543` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `prperfte` has a unit root and is non-stationary.

### 14.2.2 Absorbed Stock per Headcount

The following is the time plot output from the SAS program for the absorbed knowledge stock in the system.

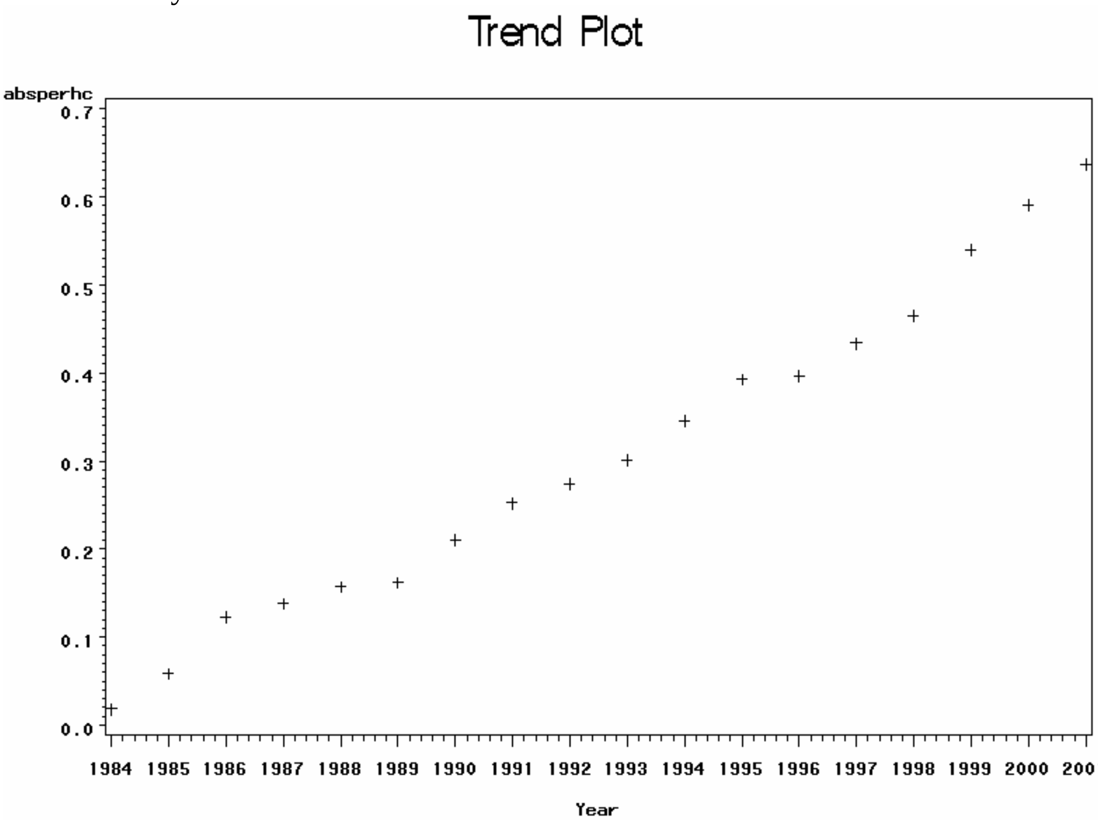


**Figure 14-6 Time plot of the Absorbed knowledge stock per Headcount personnel**

From Figure 14-6 can be seen that the time plot shows an upward trend line. We therefore make use of the “Trend” specification in the stationarity test output results.

**Table 14-11: SAS output for Phillips Perron test for variable “absperhc”**

```
                              The ARIMA Procedure

                          Name of Variable = absperhc

                       Mean of Working Series    0.549018
                       Standard Deviation        0.236942
                       Number of Observations          19

                         Phillips-Perron Unit Root Tests

Type            Lags       Rho    Pr < Rho       Tau    Pr < Tau

Zero Mean          0    1.2929      0.9324      5.49      0.9999
                   1    1.2825      0.9312      4.60      0.9999
Single Mean        0   -0.3848      0.9218     -0.91      0.7625
                   1   -0.3868      0.9217     -0.90      0.7645
Trend              0   -8.8861      0.4103     -2.71      0.2440
                   1   -9.1435      0.3877     -2.72      0.2410
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.244` for $\ell = 0$ en

`Pr < Tau = 0.241` for $\ell = 1$.

Both $p$-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `absperhc` has a unit root and is non-stationary.

### 14.2.3 Experience Stock per Headcount

The following is the time plot output from the SAS program for the Experience stock per Headcount in the system.

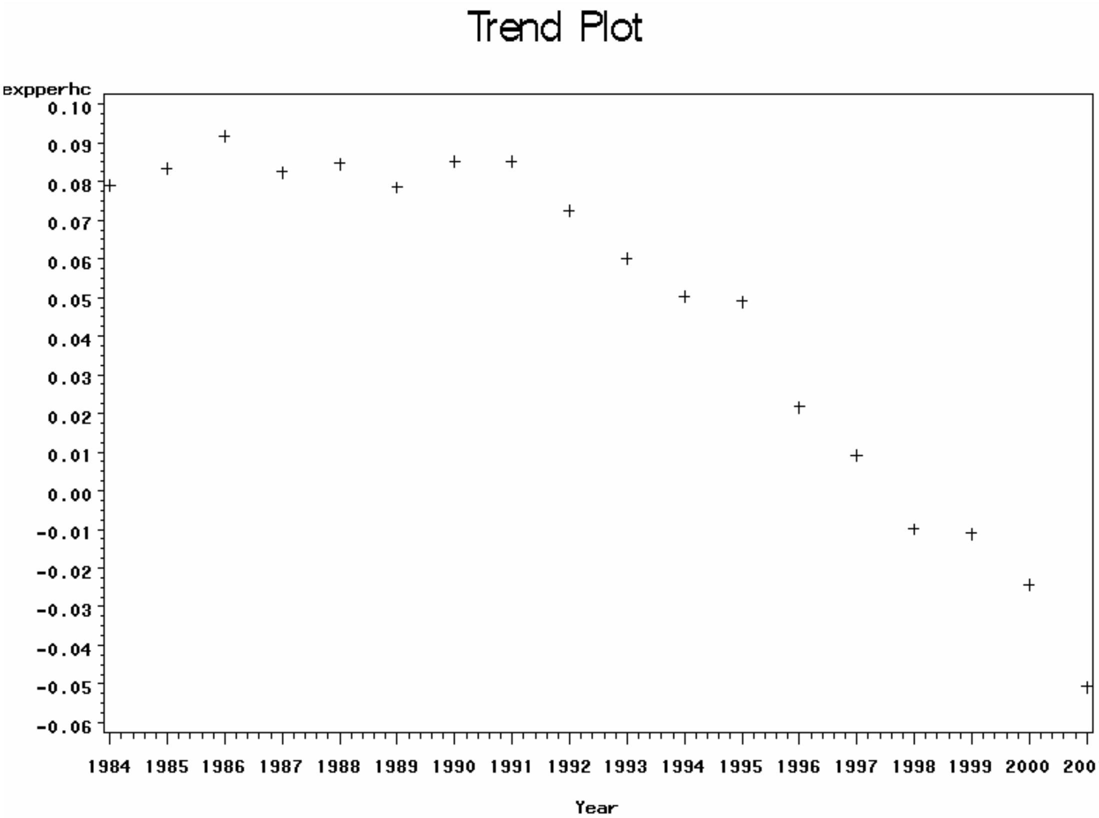


**Figure 14-7 Time plot for the "Exptotal" variable in the system**

From Figure 14-7 can be seen that the time plot shows a downward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 14-12: SAS output for Phillips Perron test for variable "Expperhc"**

The ARIMA Procedure

Name of Variable = expperhc

| | |
|---|---|
| Mean of Working Series | 0.195865 |
| Standard Deviation | 0.026819 |
| Number of Observations | 19 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -0.0565 | 0.6542 | -0.15 | 0.6181 |
| | 1 | -0.0591 | 0.6536 | -0.15 | 0.6167 |
| Single Mean | 0 | -4.5748 | 0.4334 | -1.58 | 0.4732 |
| | 1 | -5.1400 | 0.3726 | -1.66 | 0.4324 |
| Trend | 0 | -5.4205 | 0.7428 | -2.37 | 0.3785 |
| | 1 | -5.0065 | 0.7806 | -2.42 | 0.3588 |

From the Phillips Perron test output obtained from SAS we read the following values for

the probability statistics.
`Pr < Tau = 0.3785` for $\ell = 0$ en
`Pr < Tau = 0.3588` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `expperhc` has a unit root and therefore is non-stationary.

### 14.2.4 Colinearity tests

First however we should make sure that the variables are not collinear. The following is the test results obtained from SAS for the Colinearity test.

**Table 14-13: Colinearity diagnostics for the model variables**

```
                      Collinearity Diagnostics

                                           Condition
             Number      Eigenvalue            Index

                  1         2.28975          1.00000
                  2         0.70033          1.80818
                  3         0.00992         15.19053

                      Collinearity Diagnostics

                ---------Proportion of Variation---------
     Number       Intercept          absperhc          expperhc

          1         0.00332           0.00460           0.00696
          2      0.00007497           0.01905           0.05398
          3         0.99660           0.97634           0.93906
```

Larger values suggest potential near colinearity. Belsley, Kuh and Welsch (2000) recommend interpreting the Condition index greater or equal than 30 to reflect moderate to severe colinearity, worthy of further investigation. Since all the Condition indexes from the regression model is much smaller than 30, the conclusion can be made that colinearity is not a problem in this case.

***Proportion of Variation***

The variance proportion indicates for each predictor the proportion of total variance of its estimated regression coefficients associated with a particular principal component. The variance proportions suggest colinearity problems if more than one predictor has a high variance proportions of at least 0.5 for such a components suggest a problem. One should definitely be concerned when two or more ladings greater than 0.9 appear on a component with a large condition index (>30). This also does not seem to be a problem since the condition indexes all have small values.

### 14.2.5 Model estimation the rate of Paper Development in the HES

As all three variables are non-stationary, we should now fit a model and then test for cointegration in the residual

**Table 14-14: SAS code for the model estimation procedure**

```
proc autoreg data= HES.hesloglin;
model prperfte = absperhc Expperhc
/ method= ml dwprob nlag = 1;
output out=b r=residual;
run;

* consider residual *;
proc gplot data=b;
plot residual*year;
run;

* test for cointegration using arima procedure *;
proc arima data=b;
identify var=residual
stationarity=(phillips=(0,1));
run;
```

**Table 14-15: SAS output for the model estimation of Absorptive capacity in the HES**

```
                          The AUTOREG Procedure

                       Dependent Variable    prperfte


                      Ordinary Least Squares Estimates

     SSE                   0.12108175    DFE                        19
     MSE                      0.00637    Root MSE              0.07983
     SBC                   -42.744877    AIC                -46.018004
     Regress R-Square          0.9020    Total R-Square         0.9020
     Durbin-Watson             0.9014    Pr < DW                0.0003
     Pr > DW                   0.9997
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and
      Pr>DW is the p-value for testing negative autocorrelation.


                             Phillips-Ouliaris
                            Cointegration Test

                      Lags           Rho            Tau

                         1      -10.1658        -2.5256


                                             Standard                  Approx
  Variable          DF      Estimate          Error     t Value     Pr > |t|

  Intercept          1        0.0673         0.0578        1.16       0.2586
  absperhc           1        0.6672         0.0683        9.77       <.0001
  expperhc           1        1.1926         0.3490        3.42       0.0029


                         Q and LM Tests for ARCH Disturbances

                    Order            Q      Pr > Q          LM     Pr > LM

                      1         2.6944      0.1007      2.3836      0.1226
                      2         3.2668      0.1953      2.5181      0.2839
                      3         3.2901      0.3490      2.5182      0.4720
                      4         3.6991      0.4483      3.3194      0.5059
                      5         5.3127      0.3789      4.9323      0.4242
                      6         8.1806      0.2252      5.0488      0.5376
                      7        12.5365      0.0842      5.6996      0.5752
                      8        13.8929      0.0846      5.7748      0.6724
                      9        14.4766      0.1064      6.0550      0.7344
                     10        16.1185      0.0963      6.8146      0.7428
                     11        16.2700      0.1314      7.3181      0.7728
                     12        16.4044      0.1734      7.3242      0.8355
```

```
                    Maximum Likelihood Estimates

  SSE                 0.08224994    DFE                      18
  MSE                    0.00457    Root MSE            0.06760
  SBC                 -47.714313    AIC              -52.078483
  Regress R-Square        0.8178    Total R-Square       0.9334
  Durbin-Watson           1.8688    Pr < DW              0.2427
  Pr > DW                 0.7573
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and
Pr>DW is the p-value for testing negative autocorrelation.


                                       Standard                  Approx
Variable        DF      Estimate          Error    t Value    Pr > |t|

Intercept        1     -0.004500         0.0807      -0.06      0.9562
absperhc         1        0.6998         0.1220       5.73      <.0001
expperhc         1        1.5280         0.4756       3.21      0.0048
AR1              1       -0.6004         0.1938      -3.10      0.0062


               Autoregressive parameters assumed given.

                                    Standard                  Approx
Variable        DF      Estimate       Error    t Value    Pr > |t|

Intercept        1     -0.004500      0.0797      -0.06      0.9556
absperhc         1        0.6998      0.1186       5.90      <.0001
expperhc         1        1.5280      0.4756       3.21      0.0048
```

From the model estimation output obtained we can make the following conclusion:

The **R-Square 0.8178** statistic indicate that the model accounts for 81% of the variation of the percentage time spent by staff on R&D activities.

The test for autocorrelation use is the Durban Watson test statistic. The Durbin Watson test statistic is 1.8688 with (Pr < DW = 0.2427 > 0.05 and (Pr < DW = 0.7573) < 0.95. This indicates that we therefore can conclude that the autoregressive model does not have autocorrelation.

Due to the small sample size and the limited number of data points available, the heteroscedasticity test (Q and LM test for ARCH disturbances) is only interpreted up to 2 time lags. The probability for arch disturbances in the model for lags 1 and 2 are larger than 0.05. We can therefore conclude that the modelled relationship does not suffer from heteroscedasticity.

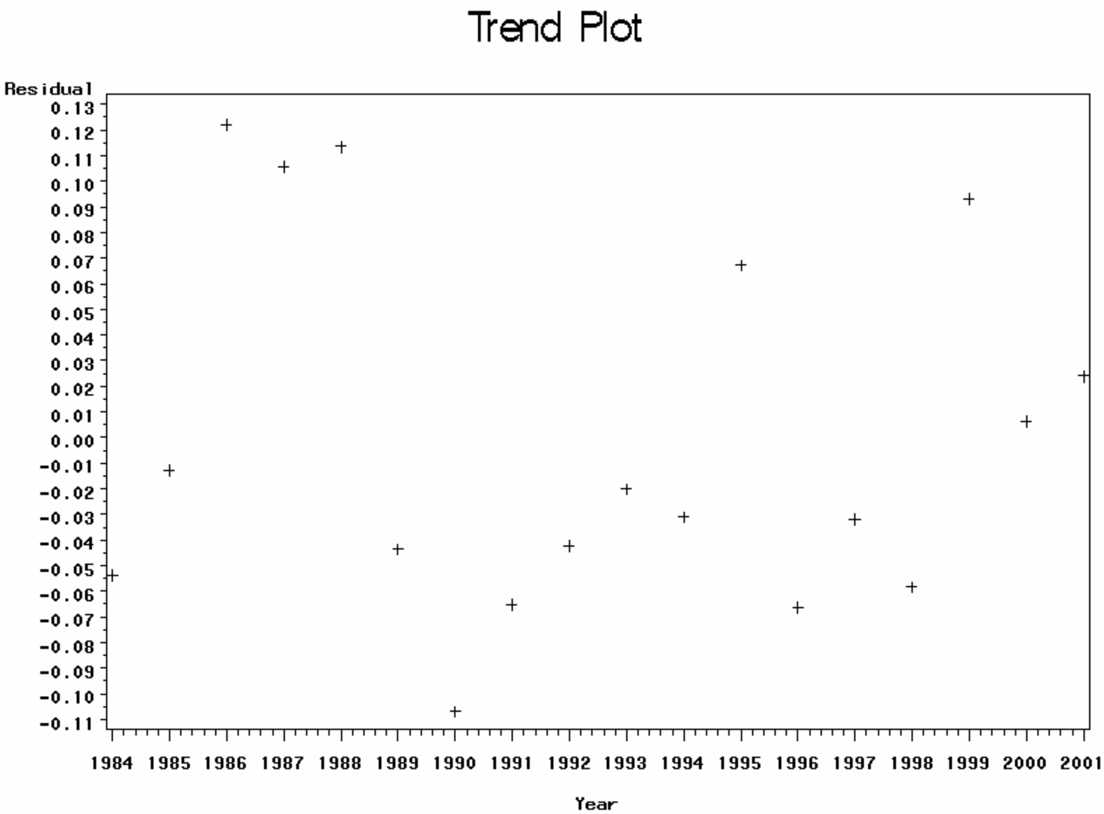


**Figure 14-8 Time plot of the residual**

From Figure 14-8 can be seen that the time plot seems to be scattered around 0. From the results we van also read the `Mean of Working Series is -0.0003`. We therefore make use of the "Zero mean" specification in the stationarity test output results.

**Table 14-16: Phillips Perron test output for the residual**

```
                    The ARIMA Procedure

                 Name of Variable = residual

              Mean of Working Series    -0.00327
              Standard Deviation        0.065914
              Number of Observations          18

             Phillips-Perron Unit Root Tests

Type           Lags         Rho    Pr < Rho        Tau    Pr < Tau

Zero Mean         0    -15.4783      0.0015      -3.66      0.0011
                  1    -15.2356      0.0017      -3.66      0.0011
Single Mean       0    -15.6068      0.0079      -3.57      0.0187
                  1    -15.3372      0.0089      -3.56      0.0190
Trend             0    -15.4989      0.0571      -3.42      0.0822
                  1    -15.1530      0.0649      -3.40      0.0841
```

For (n-1) = 2, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See **Error! Reference source not found.**). The critical value for the 7.5% level is -3.58.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.
`Tau = -3.66` for $\ell = 0$ en
`Tau = -3.66` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root with a 10% significance level, since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

## 14.3 Student-to-Staff ratio and the % time spent on R&D model

The section describes the variables included in the model to estimate the percentage time staff has left as a function of the student-to-staff relationship. The following SAS program was used.

**Table 14-17: SAS code for stationarity tests in variables "Percentage" and "studentstaff"**

```
goptions reset=all cback=white colors=(black) lfactor=2
border;
title1 'Trend Plot';
proc gplotb data = hes.studstaff;
plot (Percentage studentstaff)*year;
plot Percentage*(studentstaff);
run;

proc arima data=hes.studstaff;
identify var=Percentage stationarity=(phillips=(0,1));
identify var=studentstaff stationarity=(phillips=(0,1));
run;
```

The following sections document and explain the output obtained from the SAS program.

### 14.3.1 Student to Staff ratio in the Higher Education system

The following is the time plot output from the SAS program for the absorption rate per full time equivalent researchers in the system.

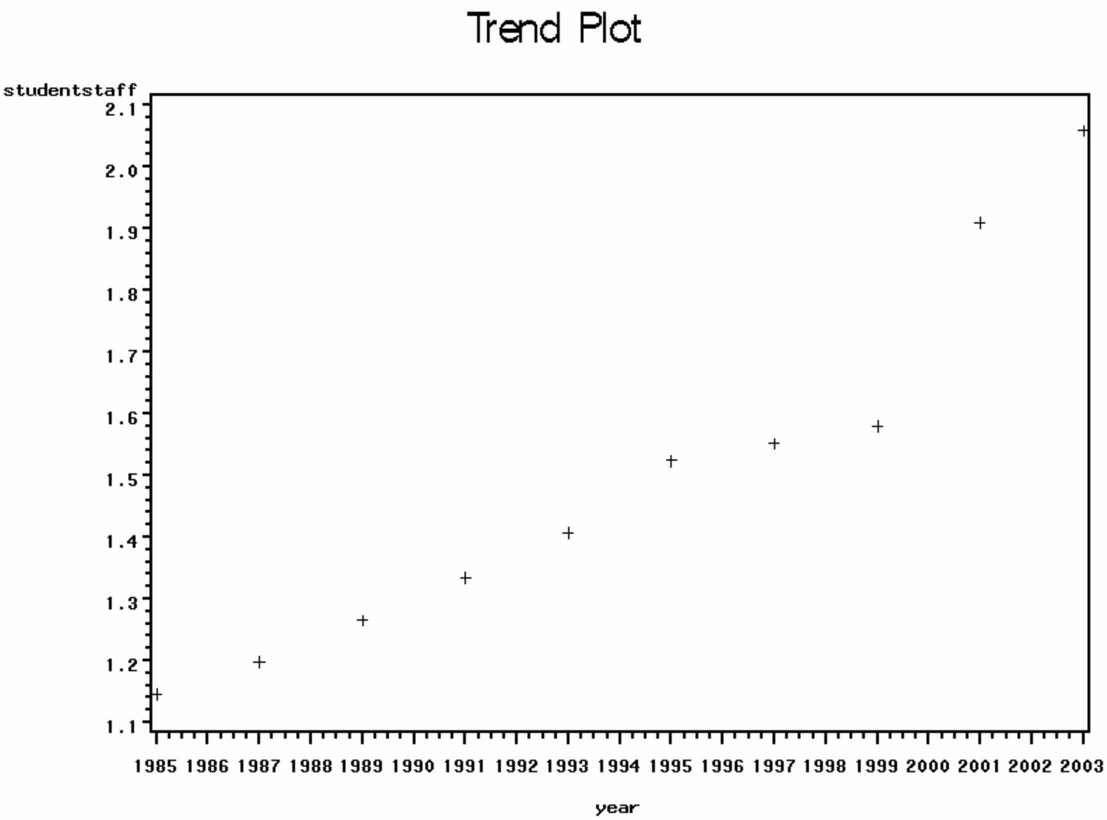


**Figure 14-9 Time plot of the Student to staff ratio in the Higher Education system**

From Figure 14-9 can be seen that the time plot shows an upward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 14-18: Phillips-Perron test output for variable "`studentstaff`"**

Name of Variable = studentstaff

| | |
|---|---|
| Mean of Working Series | 1.497557 |
| Standard Deviation | 0.282596 |
| Number of Observations | 10 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | 0.6552 | 0.8026 | 3.57 | 0.9984 |
| | 1 | 0.6573 | 0.8030 | 3.87 | 0.9989 |
| Single Mean | 0 | 1.4296 | 0.9825 | 1.15 | 0.9933 |
| | 1 | 1.6149 | 0.9854 | 1.59 | 0.9973 |
| Trend | 0 | -3.8832 | 0.8411 | -0.95 | 0.8959 |
| | 1 | -3.9095 | 0.8390 | -0.95 | 0.8949 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.8959` for $\ell$ = 0 en

`Pr < Tau = 0.8949` for $\ell$ = 1.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d$ = 1. We have to conclude that `studentstaff` has a unit root and is non-stationary.

### 14.3.2 Percentage time spent on R&D

The following is the time plot output from the SAS program for the RD Knowledge stock with Full time equivalent personnel in the system.

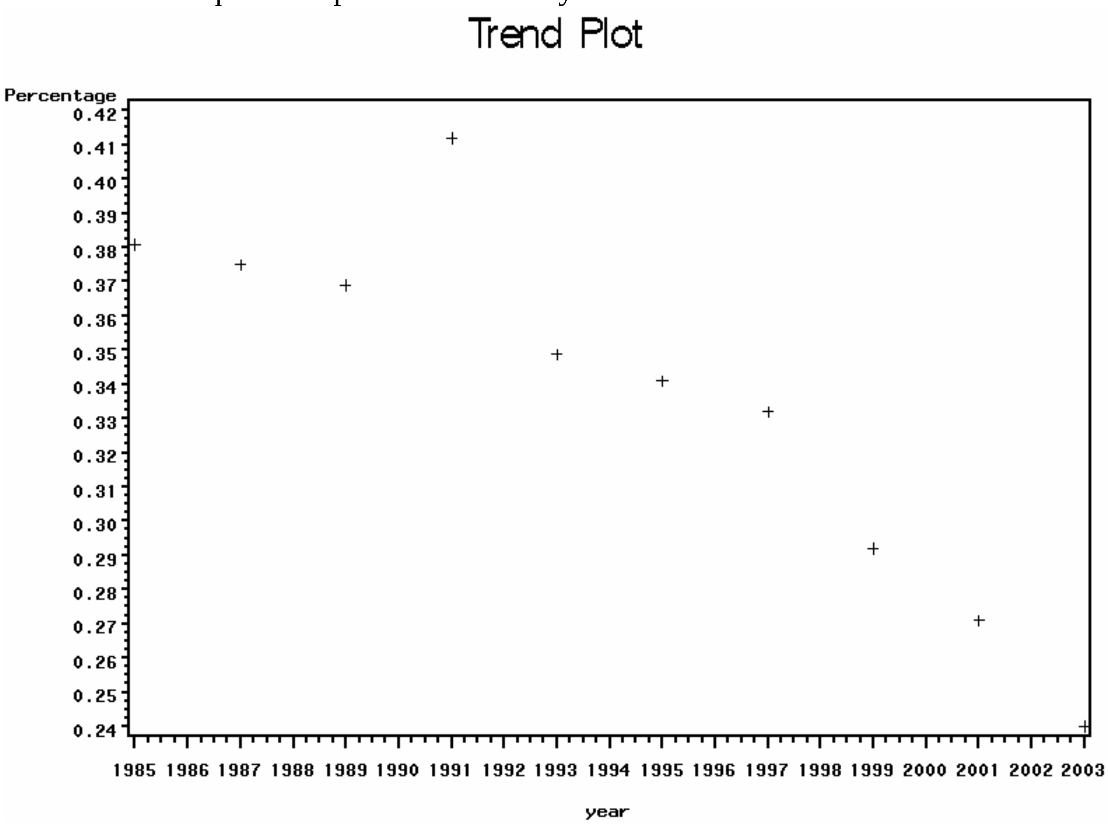


**Figure 14-10 Time plot - FTE researcher interacting with R&D knowledge**

From Figure 14-10 can be seen that the time plot shows an upward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 14-19: Phillips-Perron test output for variable "RDFTE"**

```
                              The ARIMA Procedure

                        Name of Variable = Percentage

                        Mean of Working Series     0.33618
                        Standard Deviation        0.050983
                        Number of Observations          10

                              Phillips-Perron Unit Root Tests

         Type              Lags          Rho      Pr < Rho         Tau      Pr < Tau
```

```
              Zero Mean          0      -0.3958      0.5676       -1.57       0.1021
                                 1      -0.3875      0.5693       -1.82       0.0649
              Single Mean        0       0.3426      0.9506        0.15       0.9501
                                 1       1.1173      0.9762        0.70       0.9830
              Trend              0      -6.4884      0.5616       -1.89       0.5778
                                 1      -5.3570      0.6993       -1.76       0.6379
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.5778` for $\ell$ = 0 en

`Pr < Tau = 0.6379` for $\ell$ = 1.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d$ = 1. We have to conclude that `Percentage` has a unit root and is non-stationary.

### 14.3.3 Model estimation – The time spent on R&D

As both variables are non-stationary, we should now fit a model and then test for cointegration in the residual.

**Table 14-20: SAS code for the model estimation procedure**

```
proc autoreg data= HES.hesloglin;
model absorbedR = rdFTE wsperhc
/ method= ml nlag=1 dwprob;
output out=b r=residual;
run;
```

**Table 14-21: SAS output for the model estimation of Absorptive capacity in the HES**

```
                                 The AUTOREG Procedure

                           Dependent Variable     Percentage


                           Ordinary Least Squares Estimates

                  SSE                    0.00378232     DFE                        8
                  MSE                     0.0004728     Root MSE             0.02174
                  SBC                    -45.816074     AIC               -46.421244
                  Regress R-Square           0.8545     Total R-Square        0.8545
                  Durbin-Watson              2.1775     Pr < DW               0.4613
                  Pr > DW                    0.5387
   NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
   for testing negative autocorrelation.

                                   Phillips-Ouliaris
                                  Cointegration Test

                           Lags          Rho           Tau

                              1       -9.7900       -3.2686

                                                     Standard                     Approx
                Variable        DF      Estimate        Error     t Value     Pr > |t|

                Intercept        1        0.5859       0.0371       15.80       <.0001
                studentstaff     1       -0.1668       0.0243       -6.85       0.0001


                                  The REG Procedure
```

Model: MODEL1
Dependent Variable: Percentage

Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 1 | 0.02221 | 0.02221 | 46.98 | 0.0001 |
| Error | 8 | 0.00378 | 0.00047279 | | |
| Corrected Total | 9 | 0.02599 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 0.02174 | R-Square | 0.8545 |
| Dependent Mean | 0.33618 | Adj R-Sq | 0.8363 |
| Coeff Var | 6.46789 | | |

Parameter Estimates

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | 0.58592 | 0.03708 | 15.80 | <.0001 |
| studentstaff | 1 | -0.16677 | 0.02433 | -6.85 | 0.0001 |

The REG Procedure
Model: MODEL1
Dependent Variable: Percentage

| | |
|---|---|
| Durbin-Watson D | 2.177 |
| Number of Observations | 10 |
| 1st Order Autocorrelation | -0.115 |

From the model estimation output obtained we can make the following conclusion:

The test for autocorrelation use is the Durban Watson test statistic. The Durbin Watson test statistic is 2.177 with (Pr < DW = 0.4613) > 0.05 and (Pr < DW = 0.5387) < 0.95. This indicates that we can we therefore can conclude that the model does not have autocorrelation.

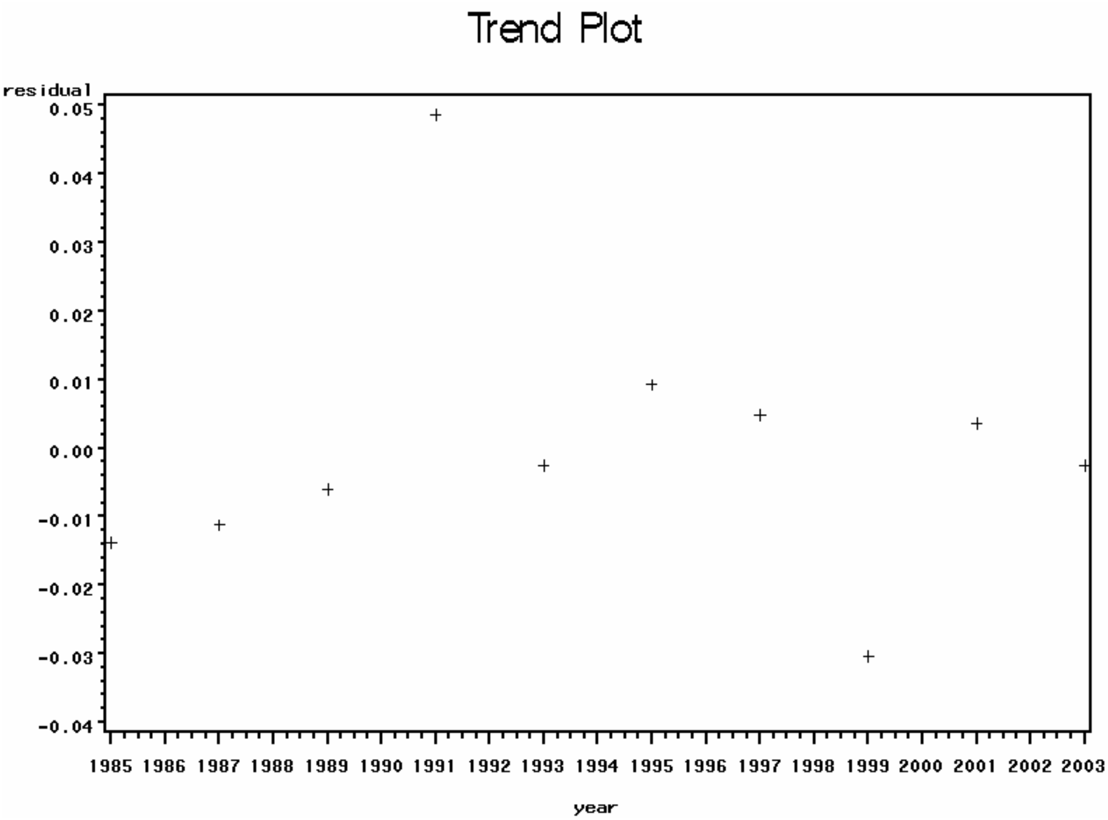


**Figure 14-11 Time plot - residual of the HES knowledge absorption**

From Figure 14-11 can be seen that the time plot seems to be scattered around 0. From the results we van also read the `Mean of Working Series 5.8E-17`. We therefore make use of the "Zero mean" specification in the stationarity test output results.

**Table 14-22: Phillips Perron tests output for the residual**

```
                     The ARIMA Procedure

                    Name of Variable = residual
                    Mean of Working Series      5.8E-17
                    Standard Deviation         0.019448
                    Number of Observations           10

                    Phillips-Perron Unit Root Tests

 Type              Lags          Rho      Pr < Rho        Tau     Pr < Tau

Zero Mean           0     -10.0352       0.0080       -3.26       0.0044
                    1      -9.7900       0.0092       -3.27       0.0044
Single Mean         0     -10.0445       0.0378       -3.06       0.0683
                    1      -9.7461       0.0445       -3.07       0.0676
Trend               0     -10.0642       0.1852       -2.89       0.2062
                    1      -9.4754       0.2329       -2.90       0.2032
```

Since an intercept is included in the model fitted, an intercept is included. For (n-1) = 1, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See table Table 14-22). The critical value for the 7.5% level is -3.20.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.
`Tau = -3.26` for $\ell = 0$ en
`Tau = -3.27` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

# 15 APPENDIX D

## 15.1 Absorption of Knowledge (Pub)

The rate at which the system is able to produce new knowledge output is computed through the contribution made form different stocks in the system. The following expression is formulated for the R&D knowledge absorption rate in the system:

- $R_{Absorptionr}$ : Absorption rate of knowledge in the system
- $S_{R\&Doutput}$ : RD output stock in the system
- $S_{FTE}$ : Stock of Full Time Equivalent people in the system
- $S_{World}$ : Available external knowledge stock (Patents)
- $S_{HC}$ : Headcount personnel employed in the system

A multiplicative model is developed for the absorption rate per Full Time Equivalent person working in the system:

$$\frac{R_{Absorptionr}}{R^{*}_{Absorption}} = f * \left(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutput}} * \frac{S_{FTE}}{S^{*}_{FTE}}\right)^{d} * \left(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}}\right)^{e} \quad \text{15-1}$$

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Absorptionr}}{R^{*}_{Absorption}}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutput}} * \frac{S_{FTE}}{S^{*}_{FTE}}\right) + e * \ln\left(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}}\right) \quad \text{15-2}$$

This is the expression used to perform the regression for estimating the parameters $d$, $e$ and $f$. The regression is executed and the following estimates for the parameters are obtained:

The section describes the variables included in the model to estimate the rate of knowledge absorption in the system. The following SAS program was used.

**Table 15-1: SAS code for stationarity tests**

```
goptions reset=all cback=white colors=(black) lfactor=2
border;
title1 'Trend Plot';
proc gplot data=Pub.paploglinear;
plot (absorbedR RDftetype wsfte)*year;
plot absorbedR*(RDftetype wsfte);
run;

* test for stationarity of the 3 series using arima procedure
*;
proc arima data=Pub.paploglinear;
identify var=absorbedR  stationarity=(phillips=(0,1));
identify var=RDftetype stationarity=(phillips=(0,1));
identify var=wsfte stationarity=(phillips=(0,1));
run;
```

The following sections document and explain the output obtained from the SAS program.

### 15.1.1 Absorption rate of knowledge in the system

The following is the time plot output from the SAS program for the absorption rate per full time equivalent researchers in the system.

$$AbsorbedR = \ln(\frac{R_{Absorptionr}}{R^{*}_{Absorption}}) \quad \textbf{15-3}$$

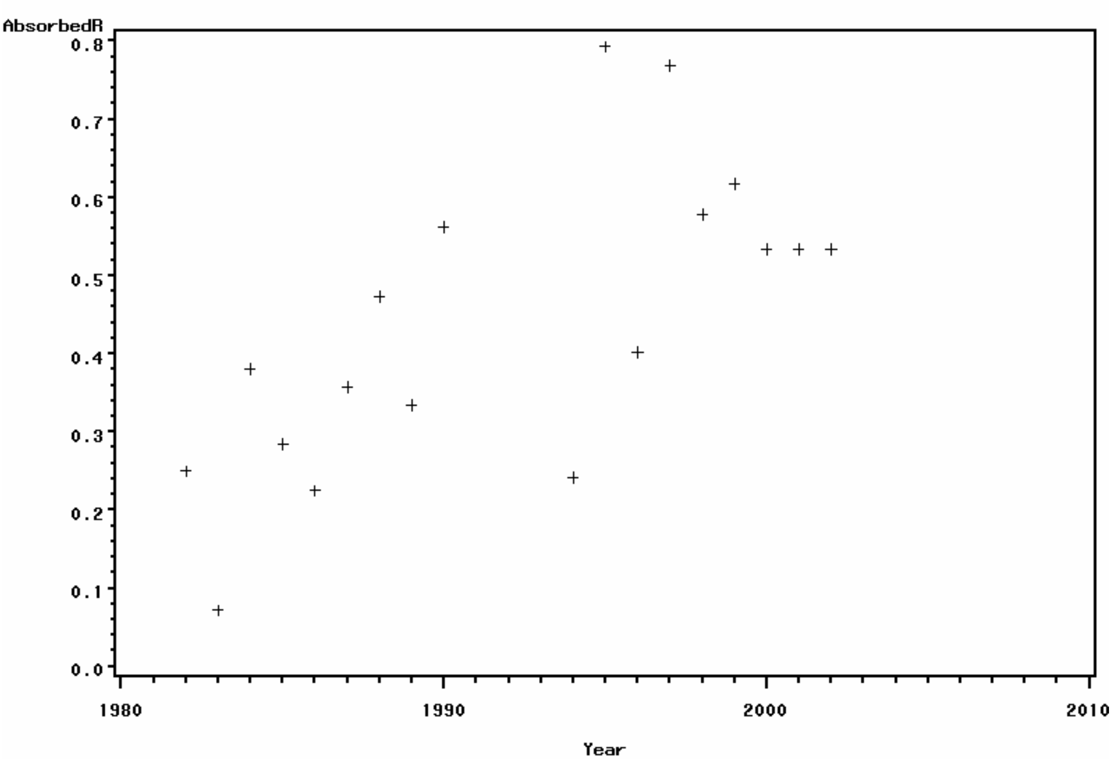


**Figure 15-1 Time plot of the absorption rate in the Public sector**

From Figure 15-1 can be seen that the time plot shows an upward trend. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-2: Phillips-Perron test output for variable "AbsorbedR"**

```
                         The ARIMA Procedure

                    Name of Variable = AbsorbedR

                  Mean of Working Series    0.286634
                  Standard Deviation        0.274244
                  Number of Observations          21

                         The ARIMA Procedure

                   Phillips-Perron Unit Root Tests

Type           Lags         Rho    Pr < Rho        Tau    Pr < Tau

Zero Mean         0     -3.7431      0.1704      -1.30      0.1719
                  1     -2.4229      0.2734      -1.01      0.2690
Single Mean       0    -12.1070      0.0420      -2.78      0.0793
                  1    -11.0751      0.0603      -2.69      0.0922
Trend             0    -15.3530      0.0761      -3.27      0.1006
                  1    -15.0457      0.0841      -3.25      0.1036
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.1006` for $\ell = 0$ en

`Pr < Tau = 0.1036` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `AbsorbedR` has a unit root and is non-stationary.

### 15.1.2 R&D Knowledge Stock and FTE researchers interaction

The following is the time plot output from the SAS program for the RD Knowledge stock with Full time equivalent personnel in the system.

$$RDfte = \ln\left(\frac{S_{R\&Doutput}}{S^*_{R\&Doutput}} * \frac{S_{FTE}}{S^*_{FTE}}\right) \qquad \textbf{15-4}$$

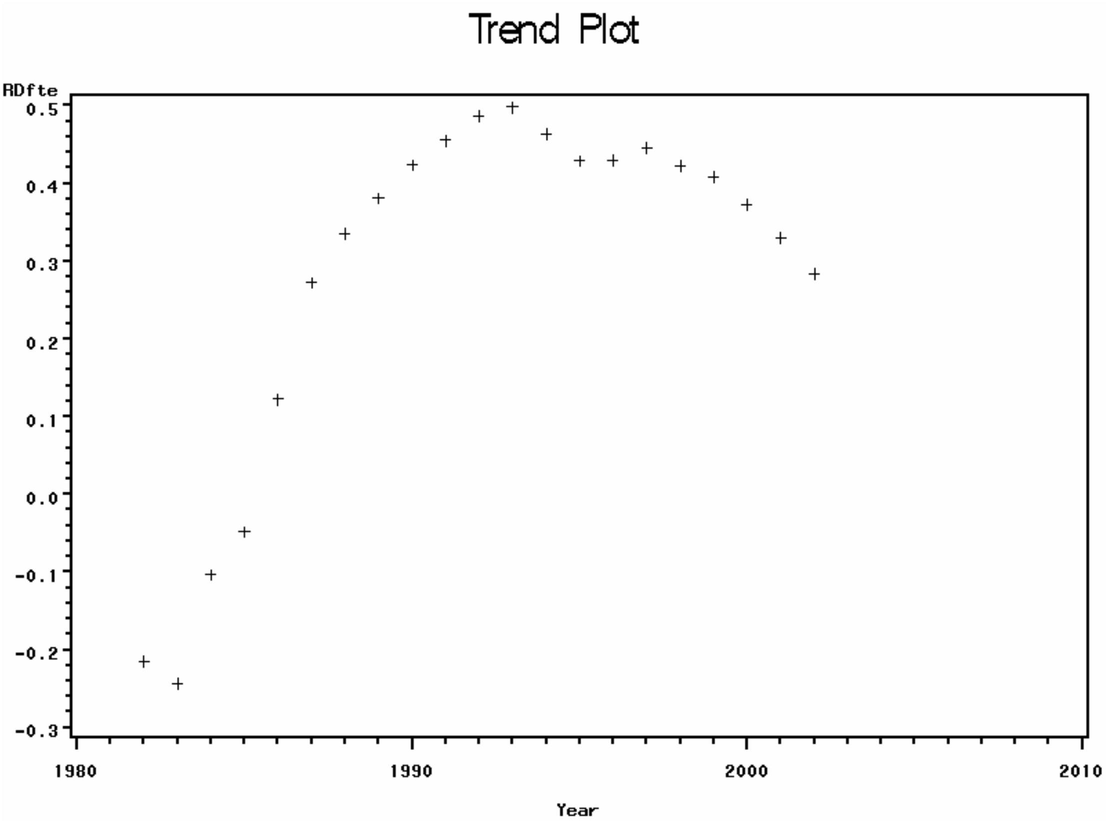


**Figure 15-2 Time plot - FTE researcher interacting with R&D knowledge**

From Figure 15-2 can be seen that the time plot shows a trend. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-3: Phillips-Perron test output for variable "RDFTE"**

Name of Variable = RDfte

| | |
|---|---|
| Mean of Working Series | 0.283461 |
| Standard Deviation | 0.229626 |
| Number of Observations | 21 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -0.2185 | 0.6177 | -0.26 | 0.5806 |
| | 1 | -0.4416 | 0.5695 | -0.41 | 0.5217 |
| Single Mean | 0 | -3.0877 | 0.6216 | -2.94 | 0.0584 |
| | 1 | -3.2346 | 0.6025 | -2.71 | 0.0894 |
| Trend | 0 | -0.4260 | 0.9895 | -0.30 | 0.9842 |
| | 1 | -0.4173 | 0.9896 | -0.30 | 0.9844 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

Pr < Tau = 0.9842 for $\ell = 0$ en

Pr < Tau = 0.9844 for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that RDFTE has a unit root and is non-stationary.

### 15.1.3 The external knowledge stock per headcount

The following is the time plot output from the SAS program for the World Knowledge Stock per R&D staff in the system.

$$Patwsperhc = \ln(\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}})$$

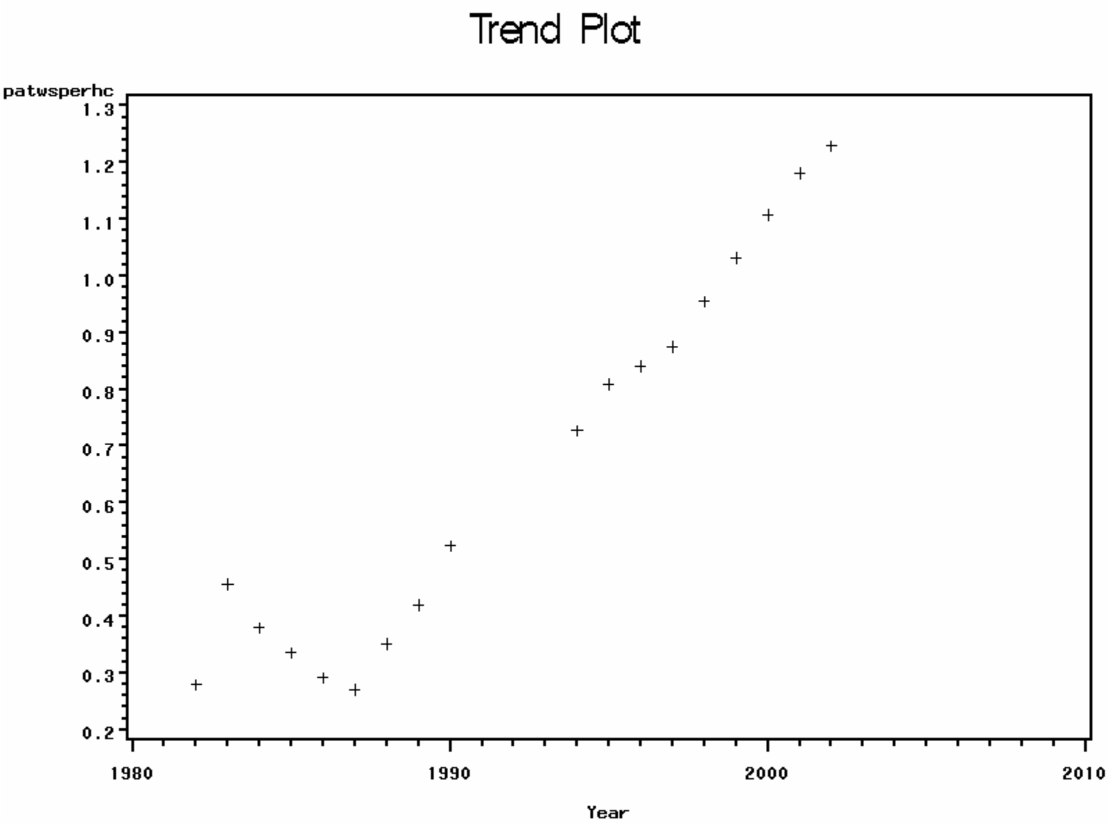


**Figure 15-3 Time plot - World stock of knowledge per HC researcher**

From Figure 15-3 can be seen that the time plot shows an upward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-4: Phillips-Perron test output for variable "Patwsperhc"**

```
Name of Variable = patwsperhc

Mean of Working Series    0.665825
Standard Deviation         0.30554
Number of Observations          21

Phillips-Perron Unit Root Tests
```

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | 1.3564 | 0.9413 | 3.59 | 0.9996 |
| | 1 | 1.3514 | 0.9408 | 3.45 | 0.9994 |
| Single Mean | 0 | 0.6846 | 0.9750 | 0.73 | 0.9897 |
| | 1 | 0.6380 | 0.9736 | 0.64 | 0.9872 |
| Trend | 0 | -4.5243 | 0.8265 | -1.53 | 0.7840 |
| | 1 | -4.7594 | 0.8075 | -1.57 | 0.7697 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.7840` for $\ell = 0$ en

`Pr < Tau = 0.7697` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `patwsperhc` has a unit root and is non-stationary.

### 15.1.4 Colinearity tests

First however we should make sure that the variables are not collinear. The following is the test results obtained from SAS for the Colinearity test.

**Table 15-5: Colinearity diagnostics for the model variables**

```
                  Collinearity Diagnostics

                                       Condition
    Number      Eigenvalue                 Index

         1         2.68537               1.00000
         2         0.23340               3.39199
         3         0.08123               5.74964

                 ---------Proportion of Variation---------
    Number        Intercept        RDfte              patwsperhc
         1        0.02158          0.03438            0.01676
         2        0.23617          0.80117            0.02376
         3        0.74226          0.16444            0.95948
```

Larger values suggest potential near colinearity. Belsley, Kuh and Welsch (2000) recommend interpreting the Condition index greater or equal than 30 to reflect moderate to severe colinearity, worthy of further investigation. Since all the Condition indexes from the regression model are much smaller than 30, the conclusion can be made that colinearity is not a problem in this case.

***Proportion of Variation***

The variance proportion indicates for each predictor the proportion of total variance of its estimated regression coefficients associated with a particular principal component. The variance proportions suggest colinearity problems if more than one predictor has a high variance proportions of at least 0.5 for such a components suggest a problem. One should definitely be concerned when two or more ladings greater than 0.9 appear on a component with a large condition index (>30). This also does not seem to be a problem since the condition indexes are all smaller than 30.

### 15.1.5 Model estimation - Absorption rate

As all three variables are non-stationary, we should now fit a model and then test for cointegration in the residual.

**Table 15-6: SAS code for the model estimation procedure**

```
proc reg data = Pub.paploglinear ;
model  arperftecontract = RDftetype worldS
/tol vif collin;
output out=a r=residual;
run;
```

**Table 15-7: SAS output for the model estimation of Absorptive capacity in the HES**

```
                    The SAS System        13:11 Monday, January 23, 2006    7

                              The AUTOREG Procedure
```

```
                                Dependent Variable    AbsorbedR

                                Ordinary Least Squares Estimates

               SSE                    0.2953922    DFE                       15
               MSE                      0.01969    Root MSE             0.14033
               SBC                   -14.223913    AIC               -16.895028
               Regress R-Square          0.5317    Total R-Square        0.5317
               Durbin-Watson             3.3536    Pr < DW               0.9979
               Pr > DW                   0.0021
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                              Q and LM Tests for ARCH Disturbances

                   Order            Q    Pr > Q            LM    Pr > LM

                     1         3.2076    0.0733        2.9992     0.0833
                     2         3.7507    0.1533        2.9994     0.2232
                     3         3.8340    0.2800        2.9994     0.3917
                     4         7.5941    0.1076        6.0103     0.1984
                     5        10.4175    0.0642        6.0293     0.3034
                     6        13.7073    0.0331        6.3609     0.3840
                     7        15.7191    0.0278        6.8765     0.4418
                     8        15.7699    0.0458        8.3467     0.4004
                     9        15.8418    0.0703       10.2484     0.3308
                    10        15.8851    0.1030       13.4042     0.2019
                    11        16.1797    0.1346       14.5944     0.2018
                    12        16.2023    0.1821       15.1744     0.2320

                                                   Standard                 Approx
           Variable          DF      Estimate         Error    t Value    Pr > |t|

           Intercept          1        0.2143        0.0750       2.86      0.0120
           RDfte              1        0.3880        0.1719       2.26      0.0393
           patwsperhc         1        0.1936        0.1211       1.60      0.1308

                                  Estimates of Autocorrelations

  Lag    Covariance     Correlation    -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

   0         0.0164        1.000000    |                    |********************|
   1        -0.0112       -0.685361    |      **************|                    |

                  The SAS System        13:11 Monday, January 23, 2006   8

                                   The AUTOREG Procedure

                                Preliminary MSE     0.00870

                          Estimates of Autoregressive Parameters

                                                    Standard
                         Lag      Coefficient          Error     t Value

                           1         0.685361       0.194621        3.52

              Algorithm converged.

                                Maximum Likelihood Estimates

               SSE                   0.15202524    DFE                       14
               MSE                      0.01086    Root MSE             0.10421
               SBC                   -22.691358    AIC               -26.252845
               Regress R-Square          0.8553    Total R-Square        0.7590
               Durbin-Watson             1.9361    Pr < DW               0.2412
               Pr > DW                   0.7588
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                                                   Standard                 Approx
           Variable          DF      Estimate         Error    t Value    Pr > |t|

           Intercept          1        0.1991        0.0350       5.70      <.0001
           RDfte              1        0.3787        0.0819       4.62      0.0004
           patwsperhc         1        0.2187        0.0577       3.79      0.0020
           AR1                1        0.6712        0.1909       3.52      0.0034

                          Autoregressive parameters assumed given.

                                                   Standard                 Approx
           Variable          DF      Estimate         Error    t Value    Pr > |t|

           Intercept          1        0.1991        0.0350       5.70      <.0001
           RDfte              1        0.3787        0.0819       4.62      0.0004
           patwsperhc         1        0.2187        0.0576       3.79      0.0020
```

From the model estimation output obtained we can make the following conclusion:

The test for autocorrelation use is the Durban Watson test statistic. The `Durbin Watson` test statistic is `1.9054 with (Pr < DW = 0.2205) > 0.05 and (Pr < DW = 0.7795) < 0.95`. This indicates that we can we therefore can conclude that the autoregressive model does not have autocorrelation.

Due to the small sample size and the limited number of data points available, the heteroscedasticity test is only interpreted up to 2 time lags. The probability for arch disturbances in the model for lags 1 and 2 are larger than 0.05. We can therefore conclude that the modelled relationship does not suffer from heteroscedasticity.

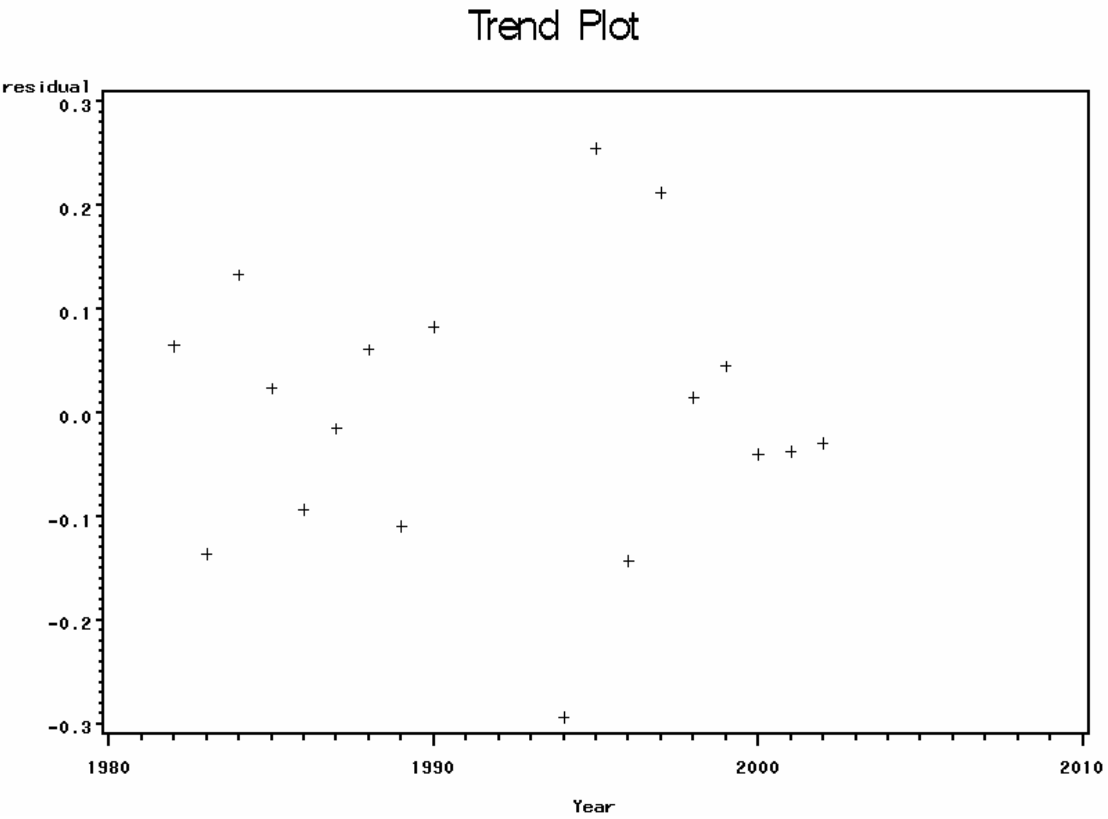


**Figure 15-4 Time plot - residual of the HES knowledge absorption**

From Figure 15-4 can be seen that the time plot seems to be scattered around 0. From the results we van also read the `Mean of Working Series -0.00167`. We therefore make use of the "Zero mean" specification in the stationarity test output results.

**Table 15-8: Test for stationarity of the residual**

```
                   The ARIMA Procedure

                Name of Variable = residual

            Mean of Working Series    3.46E-17
            Standard Deviation        0.128104
            Number of Observations          18

                 Phillips-Perron Unit Root Tests

Type            Lags   Rho        Pr < Rho    Tau       Pr < Tau

Zero Mean        0    -28.6839    <.0001     -9.39     <.0001
                 1    -29.0391    <.0001     -9.15     <.0001
Single Mean      0    -28.6795    <.0001     -9.10     <.0001
                 1    -29.0411    <.0001     -8.86     <.0001
Trend            0    -28.7210    <.0001     -8.85     0.0005
                 1    -29.0497    <.0001     -8.64     0.0005
```

Since an intercept is included in the model fitted, an intercept is included in the analysis. For (n-1) = 2, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See **Error! Reference source not found.**). The critical value for the 1% level is -4.31.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Tau = -4.84` for $\ell = 0$ en

`Tau = -4.84` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

## 15.2 Creation of new knowledge – Scientific papers (Public sector)

The rate at which the system is able to produce new knowledge output is computed through the contribution made form different stocks in the system. The following expression is formulated for the R&D output produced by human resources in the Public sector:

- $R_{Paper}$ : Rate at which R&D output is generated in the system (Papers)
- $S_{FTE}$ : Ratio of full time equivalent R&D staff in the system
- $S_{Absorbed}$ : Absorbed knowledge stock in the system.
- $A_{Contract}$ : The ration of research directed towards contract research
- $A_{Basi\&Applied}$ : The ratio of research directed toward Basic and Applied research

A multiplicative model is developed for the development rate of papers per full time person working in the system:

$$\frac{R_{Paper}}{R^*_{Paper}} = d * \left(\frac{S_{Absorbed}}{S_{Absorbed}} * \frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{Basic\&Applied}}{A^*_{Bsic\&Applied}}\right)^a \left(\frac{A_{State}}{A^*_{State}}\right)^b \left(\frac{S_{FTE}}{S^*_{FTE}}\right)^c \qquad \textbf{15-5}$$

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Paper}}{R^*_{Paper}}\right) = \ln(d) + a * \ln\left(\frac{S_{Absorbed}}{S^*_{Absorbed}} * \frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{Basic\&Applied}}{A^*_{Bsic\&Applied}}\right) + b * \ln\left(\frac{A_{State}}{A^*_{State}}\right) + \mathbf{c}* \ln\left(\frac{S_{FTE}}{S^*_{FTE}}\right) \quad \textbf{15-6}$$

This is then the expression used to perform the regression for estimating the parameters $a, b, c$ and $d$. The regression is executed and the following estimates for the parameters are obtained:

The section describes the variables included in the model to estimate the rate of knowledge creation in the system. The following SAS program was used.

**Table 15-9: SAS program code for stationarity tests and trend plots**

```
goptions reset=all cback=white colors=(black) lfactor=2 border;
title1 'Trend Plot';
proc gplot data=Pub.paploglinear;
plot (RDpapersr absftetype ftetot percstate)*year;

run;

* test for stationarity of the 3 series using arima procedure *;
proc arima data=Pub.paploglinear;
identify var=RDpapersr stationarity=(phillips=(0,1));
identify var=absftetype stationarity=(phillips=(0,1));
identify var=ftetot stationarity=(phillips=(0,1));
identify var=percstate stationarity=(phillips=(0,1));
run;
```

The following sections document and explain the output obtained from the SAS program.

### 15.2.1 R&D output produced

The following is the time plot output from the SAS program for the R&D output (papers) created in the system.

$$RDPapersR = \ln\left(\frac{R_{Paper}}{R^*_{Paper}}\right) \quad \textbf{15-7}$$

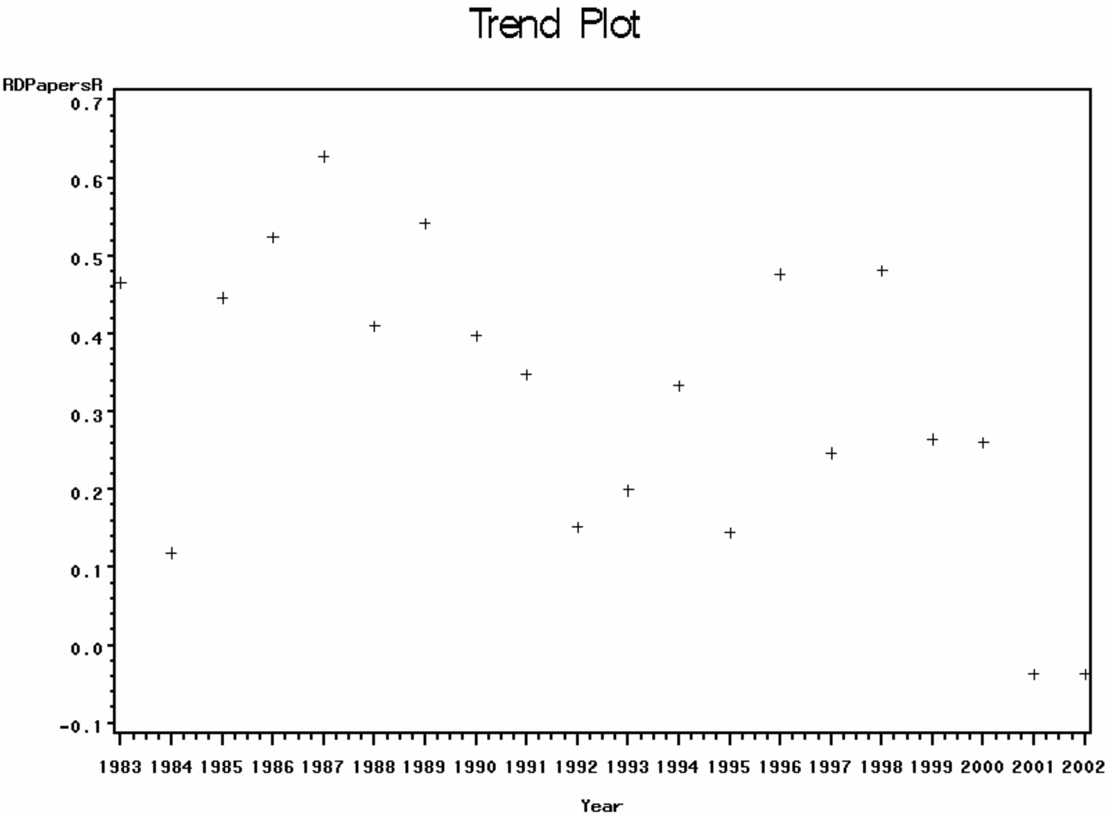


**Figure 15-5 Time plot of the Knowledge creation rate per FTE**

From Figure 15-5 can be seen that the time plot shows a downward trend. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-10: SAS output for Phillips Perron test for variable "RDpapersr"**

```
                      The ARIMA Procedure
                   Name of Variable = RDPapersR

                 Mean of Working Series    0.318457
                 Standard Deviation        0.182812
                 Number of Observations          20

                      The ARIMA Procedure

                 Phillips-Perron Unit Root Tests

 Type           Lags       Rho     Pr < Rho       Tau     Pr < Tau

Zero Mean         0     -3.5094     0.1848      -1.55      0.1098
                  1     -2.5793     0.2572      -1.44      0.1347
Single Mean       0    -11.6431     0.0475      -2.46      0.1399
                  1    -11.1338     0.0570      -2.41      0.1526
Trend             0    -16.0664     0.0545      -3.25      0.1040
                  1    -15.6509     0.0629      -3.23      0.1085
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.1040` for $\ell = 0$ en

`Pr < Tau = 0.1085` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `RDpapersR` has a unit root and is non-stationary.

### 15.2.2 Absorbed Knowledge stock

The variable is the Absorbed knowledge stock and FTE R&D staff multiplied with the % time they are spending on Basic and Applied research.

$$Variable = absftetype = \ln(\frac{S_{Absorbed}}{S_{Absorbed}} * \frac{S_{FTE}}{S^{*}_{FTE}} * \frac{A_{Basic\&Applied}}{A^{*}_{Bsic\&Applied}}) \quad \textbf{15-8}$$

The following is the time plot output from the SAS program for the Absorbed Knowledge stock and the interaction with the FTE R&D staff focussing on Basic and Applied research.

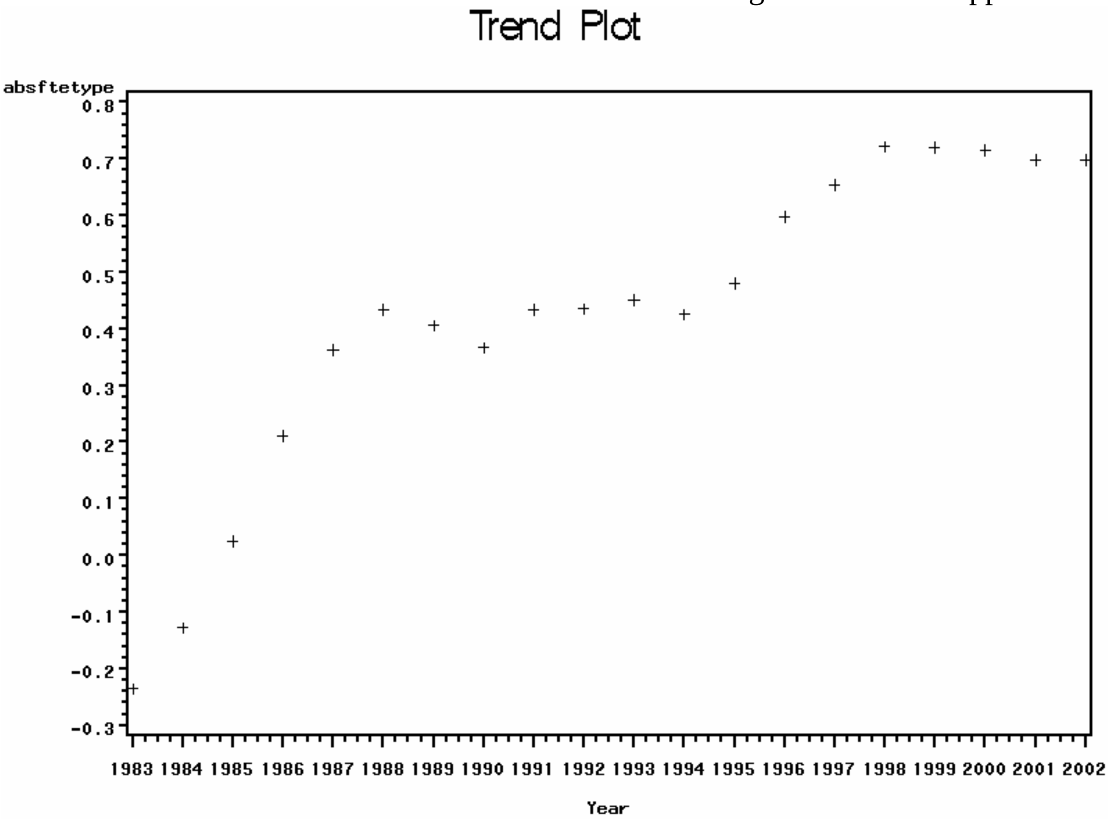


**Figure 15-6 Time plot - Absorbed knowledge stock per HC**

From Figure 15-6 can be seen that the time plot shows a trend line. We therefore make use of the “Trend” specification in the stationarity test output results.

**Table 15-11: SAS output for Phillips Perron test for variable “Absftetype”**

```
Name of Variable = absftetype

Mean of Working Series    0.424206
Standard Deviation        0.269425
Number of Observations          20

                    Phillips-Perron Unit Root Tests

Type           Lags        Rho    Pr < Rho       Tau    Pr < Tau

Zero Mean         0     0.6314      0.8221      0.85      0.8857
                  1     0.4476      0.7789      0.46      0.8034
Single Mean       0    -3.2008      0.6051     -3.81      0.0104
                  1    -3.3340      0.5878     -3.34      0.0274
Trend             0    -4.9511      0.7876     -2.38      0.3754
                  1    -5.6666      0.7222     -2.34      0.3968
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.
Pr < Tau = 0.7748 for $\ell = 0$ en
Pr < Tau = 0.7764 for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that Absftetype has a unit root and is non-stationary.

### 15.2.3 FTE total

The following is the time plot output from the SAS program for the Full time equivalent R&D staff in the system.

$$FTEtot = \ln(\frac{S_{FTE}}{S^*_{FTE}}) \qquad \textbf{15-9}$$

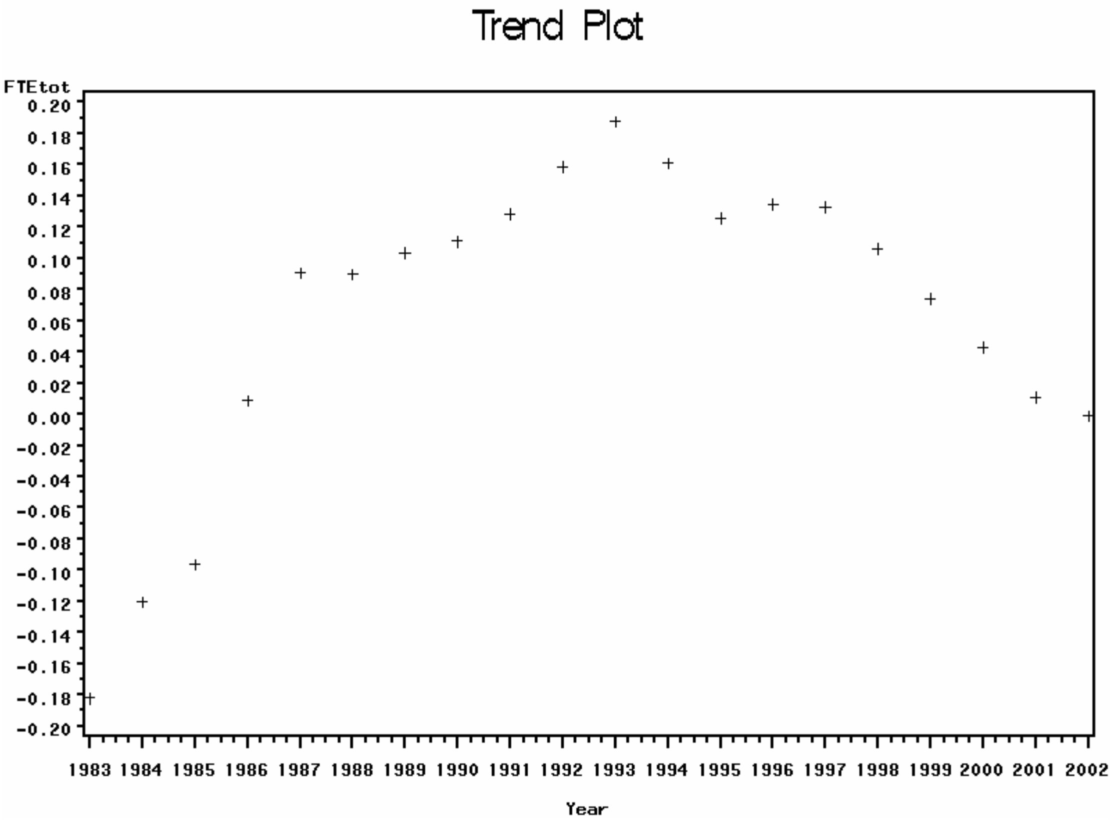


**Figure 15-7 Time plot for the FTE variable in the system**

From Figure 15-7 can be seen that the time plot shows a trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-12: SAS output for Phillips Perron test for variable "Ftetot"**

Name of Variable = FTEtot

| | |
|---|---|
| Mean of Working Series | 0.063345 |
| Standard Deviation | 0.097222 |
| Number of Observations | 20 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -2.2394 | 0.2915 | -1.59 | 0.1021 |
| | 1 | -2.8032 | 0.2372 | -1.58 | 0.1037 |
| Single Mean | 0 | -4.5078 | 0.4436 | -3.11 | 0.0426 |
| | 1 | -4.9578 | 0.3943 | -2.83 | 0.0728 |
| Trend | 0 | -2.0418 | 0.9584 | -1.55 | 0.7748 |
| | 1 | -2.0614 | 0.9578 | -1.54 | 0.7764 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

Pr < Tau = 0.7748 for $\ell = 0$ en

Pr < Tau = 0.7764 for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d$ = 1. We have to conclude that `FTEtot` has a unit root and therefore is non-stationary.

### 15.2.4 Percentage R&D funding from the State

The following is the time plot output from the SAS program for the percentage of total funding directed towards non-contract research.

$$Percstate = \ln(\frac{A_{State}}{A^*_{State}})$$

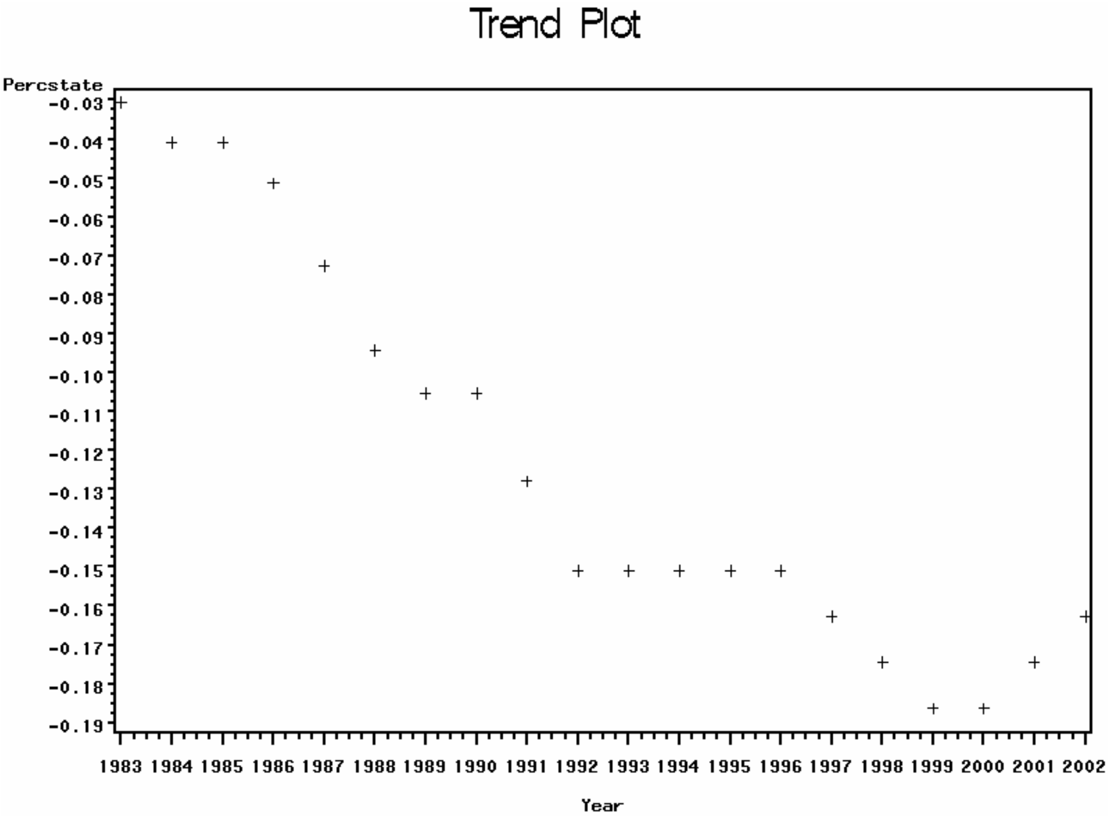


**Figure 15-8 Time plot - "Percentage non-contract funding" variable**

From Figure 15-8 can be seen that the time plot shows a downwards trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-13: SAS output for Phillips Perron test for variable "Percstate"**

Name of Variable = Percstate

| | |
|---|---|
| Mean of Working Series | -0.12347 |
| Standard Deviation | 0.050749 |
| Number of Observations | 20 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | 0.9546 | 0.8874 | 1.91 | 0.9825 |
| | 1 | 0.9006 | 0.8779 | 1.49 | 0.9610 |
| Single Mean | 0 | -0.9254 | 0.8793 | -1.20 | 0.6507 |
| | 1 | -0.9873 | 0.8735 | -1.16 | 0.6694 |
| Trend | 0 | -1.5686 | 0.9723 | -0.59 | 0.9680 |
| | 1 | -2.3244 | 0.9512 | -0.80 | 0.9483 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.9680` for $\ell = 0$ en

`Pr < Tau = 0.9483` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `Percstate` has a unit root and therefore is non-stationary.

### 15.2.5 Colinearity tests

First however we should make sure that the variables are not collinear. The following is the test results obtained from SAS for the Colinearity test.

**Table 15-14: Colinearity diagnostics for the model variables**

Collinearity Diagnostics

| Number | Eigenvalue | Condition Index |
|---|---|---|
| 1 | 3.39433 | 1.00000 |
| 2 | 0.48561 | 2.64383 |
| 3 | 0.10669 | 5.64036 |
| 4 | 0.01337 | 15.93298 |

| | ---------------Proportion of Variation---------------- | | | |
|---|---|---|---|---|
| Number | Intercept | absftetype | FTEtot | Percstate |
| 1 | 0.00675 | 0.00323 | 0.02198 | 0.00176 |
| 2 | 0.05268 | 0.00000497 | 0.55275 | 0.00162 |
| 3 | 0.35634 | 0.15964 | 0.42527 | 0.00892 |
| 4 | 0.58423 | 0.83713 | 1.876643E-8 | 0.98771 |

Larger values suggest potential near colinearity. Belsley, Kuh and Welsch (2000) recommend interpreting the Condition index greater or equal than 30 to reflect moderate to severe colinearity, worthy of further investigation. Since all the Condition indexes from the regression model is much smaller than 30, the conclusion can be made that colinearity is not a problem in this case.

***Proportion of Variation***

The variance proportion indicates for each predictor the proportion of total variance of its estimated regression coefficients associated with a particular principal component. The variance proportions suggest colinearity problems if more than one predictor has a high variance proportions of at least 0.5 for such a components suggest a problem. One should definitely be concerned when two or more ladings greater than 0.9 appear on a component with a large condition index (>30). This also does not seem to be a problem since the condition indexes are all small values.

### 15.2.6 Model estimation the rate of Paper Development in the PubS

As all three variables are non-stationary, we should now fit a model and then test for cointegration in the residual.

**Table 15-15: SAS code for the model estimation procedure**

```
/*r2 = 58 all p's significant*/
proc reg data = Pub.paploglinear ;
model RDPapersR =  absftetype  ftetot percstate
/tol vif collin spec dw;
output out=b r=residual;
run;

proc reg data = Pub.paploglinear ;
model RDPapersR =  absftetype  ftetot percstate
/tol vif collin spec dw;
output out=b r=residual;
run;

proc gplot data=b;
plot residual*year;
run;

proc arima data=b;
identify var=residual
stationarity=(phillips=(0,1));
run;
```

**Table 15-16: SAS output for the model estimation of Absorptive capacity in the HES**

```
                         Dependent Variable: RDPapersR

                     Number of Observations Read          20
                     Number of Observations Used          20

                              Analysis of Variance

                                    Sum of           Mean
 Source                    DF      Squares         Square    F Value    Pr > F

 Model                      3      0.32021        0.10674       4.90    0.0133
 Error                     16      0.34820        0.02176
 Corrected Total           19      0.66840

                 Root MSE              0.14752     R-Square     0.4791
                 Dependent Mean        0.31846     Adj R-Sq     0.3814
                 Coeff Var            46.32375

                              Parameter Estimates

                   Parameter     Standard                             Variance
Variable     DF     Estimate        Error    t Value    Pr > |t|    Tolerance     Inflation

Intercept     1      0.69529      0.10741       6.47      <.0001            .             0
absftetype    1      0.49421      0.33156       1.49      0.1555      0.13636       7.33352
FTEtot        1      0.87438      0.45615       1.92      0.0733      0.55327       1.80744
Percstate     1      5.19868      1.70890       3.04      0.0078      0.14467       6.91208

                            Test of First and Second
```

```
                         Moment Specification

                    DF    Chi-Square    Pr > ChiSq

                     9         11.97        0.2151

               Durbin-Watson D                1.959
               Number of Observations            20
               1st Order Autocorrelation     -0.117

                Dependent Variable    RDPapersR

                Ordinary Least Squares Estimates

 SSE                   0.34819932    DFE                      16
 MSE                      0.02176    Root MSE            0.14752
 SBC                   -12.273779    AIC              -16.256708
 Regress R-Square          0.4791    Total R-Square       0.4791
 Durbin-Watson             1.9593    Pr < DW              0.1850
 Pr > DW                   0.8150
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-
value for testing negative autocorrelation.

                          Phillips-Ouliaris
                         Cointegration Test

                Lags           Rho           Tau

                   1      -22.9280       -4.7653

                                        Standard                  Approx
 Variable          DF      Estimate        Error    t Value    Pr > |t|

 Intercept          1        0.6953       0.1074       6.47      <.0001
 absftetype         1        0.4942       0.3316       1.49      0.1555
 FTEtot             1        0.8744       0.4561       1.92      0.0733
 Percstate          1        5.1987       1.7089       3.04      0.0078
```

From the model estimation output obtained we can make the following conclusion:

The R-Square 0.4791 statistic indicate that the model accounts for 47.9% of the variation of the papers produced in the Public sector.

The test for autocorrelation use is the Durban Watson test statistic. The Durbin Watson test statistic is 1.9593 with (Pr < DW = 0.1850 > 0.05 and (Pr < DW = 0.8150) < 0.95. This indicates that we therefore can conclude that the autoregressive model does not have autocorrelation.

Chi-square tests for the first moment specification indicates that the model does not have heteroscedastic errors. The SPEC option performs a model specification test. The null hypothesis for this test maintains that the errors are homoscedastic, independent of the regressor and that several technical assumptions about the model specification are valid. With Pr = 0.2151 we fail to reject the null hypothesis. We can therefore conclude that no heteroscedasiticity is present in the model.

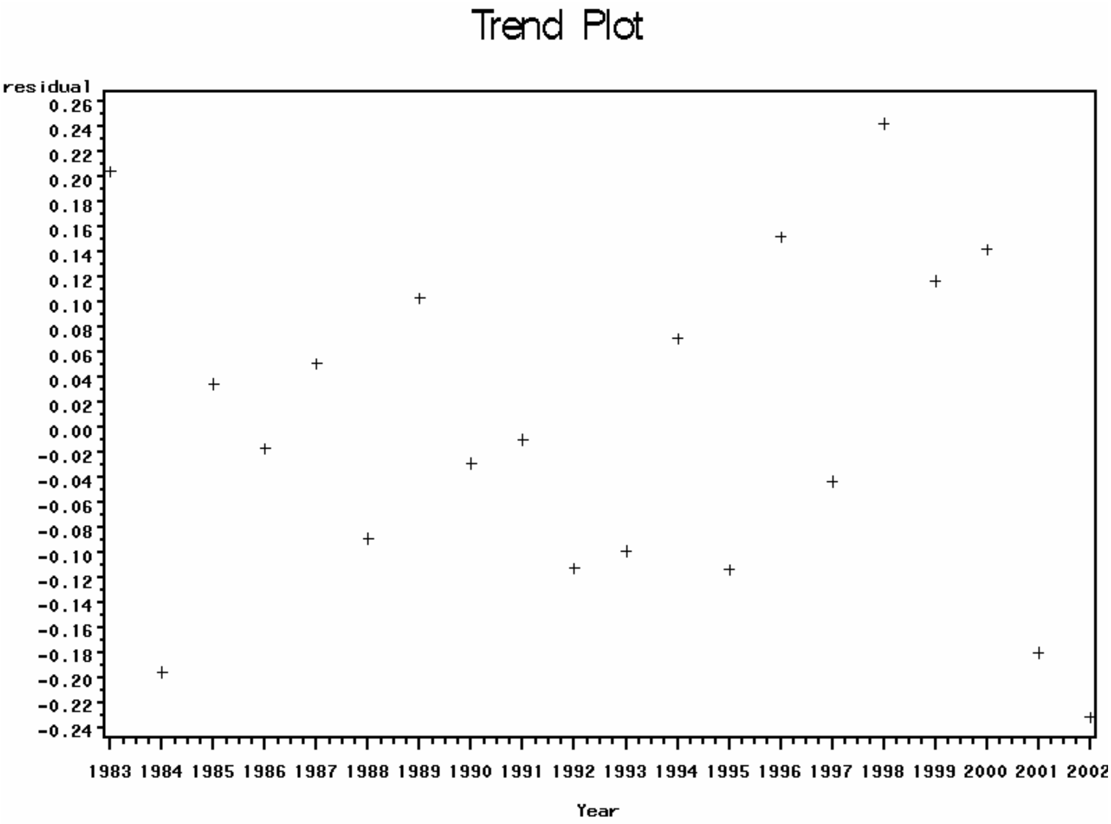


**Figure 15-9 Time plot - "Percentage non-contract funding" variable**

From **Error! Reference source not found.** can be seen that the time plot seems to be scattered around 0. From the results we van also read the `Mean of Working Series is 2.78E-17`. We therefore make use of the "Zero mean" specification in the stationarity test output results.

**Table 15-17: SAS output for residual stationarity test**

```
                          The ARIMA Procedure

                      Name of Variable = residual

                  Mean of Working Series     2.78E-17
                  Standard Deviation         0.131947
                  Number of Observations           20

                     Phillips-Perron Unit Root Tests

 Type              Lags         Rho    Pr < Rho         Tau    Pr < Tau

 Zero Mean            0    -21.6248      <.0001       -4.78      <.0001
                      1    -22.9280      <.0001       -4.77      <.0001
 Single Mean          0    -21.4877      0.0005       -4.61      0.0020
                      1    -22.8079      0.0003       -4.60      0.0020
 Trend                0    -21.6749      0.0054       -4.50      0.0107
                      1    -22.9344      0.0028       -4.51      0.0107
```

For (n-1) = 3, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See table Table 15-17). The critical value for the 5% level is -4.11.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Tau = -4.78` for $\ell = 0$ en

`Tau = -4.77` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root with a 5% significance level, since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

## 15.3 Creation of new knowledge – Patents (Public sector)

The rate at which the system is able to produce new knowledge output is computed through the contribution made form different stocks in the system. The following expression is formulated for the R&D output productivity per FTE researcher working in the system:

- $R_{Patents}$ : R&D output rate in the system (Patents)
- $S_{FTE}$ : FTE researchers in the system
- $A_{ExpDev}$ : Fraction of funding directed towards Experimental Development.
- $A_{State}$ : The ratio of research expenditure funded by the state – assumed to be directed towards non-contract research.

A multiplicative model is developed for the development rate of papers per full time person working in the system:

$$\frac{R_{Patent}}{R^*_{Patent}} = b*(\frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{ExpDev}}{A^*_{ExpDev}} * \frac{A_{Statet}}{A^*_{State}})^a \qquad \textbf{15-10}$$

This expression is linearised by taking the log-linear form:

$$\ln(\frac{R_{Patent}}{R^*_{Patent}}) = \ln(b) + a*\ln(\frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{ExpDev}}{A^*_{ExpDev}} * \frac{A_{Statet}}{A^*_{State}}) \qquad \textbf{15-11}$$

This is then the expression used to perform the regression for estimating the parameters $a$ and $b$. The regression is executed and the following estimates for the parameters are obtained:

The section describes the variables included in the model to estimate the rate of knowledge creation in the system. The following SAS program was used.

**Table 15-18: SAS program code for stationarity tests and trend plots**

```
goptions reset=all cback=white colors=(black) lfactor=2
border;
title1 'Trend Plot';
proc gplot data=Pub.patloglinear;
plot (RDout ftepattypestate )*year;
run;
```

```
* test for stationarity of the 3 series using arima procedure
*;
proc arima data=Pub.patloglinear;
identify var=RDout stationarity=(phillips=(0,1));
identify var=ftepattypestate  stationarity=(phillips=(0,1));
run;
```

The following sections document and explain the output obtained from the SAS program.

### 15.3.1 R&D patent output produced

The following is the time plot output from the SAS program for the R&D output (papers) created per full time equivalent researcher in the system.

$$Rdout = \ln(\frac{R_{Patent}}{R^*_{Patent}}) \qquad \textbf{15-12}$$

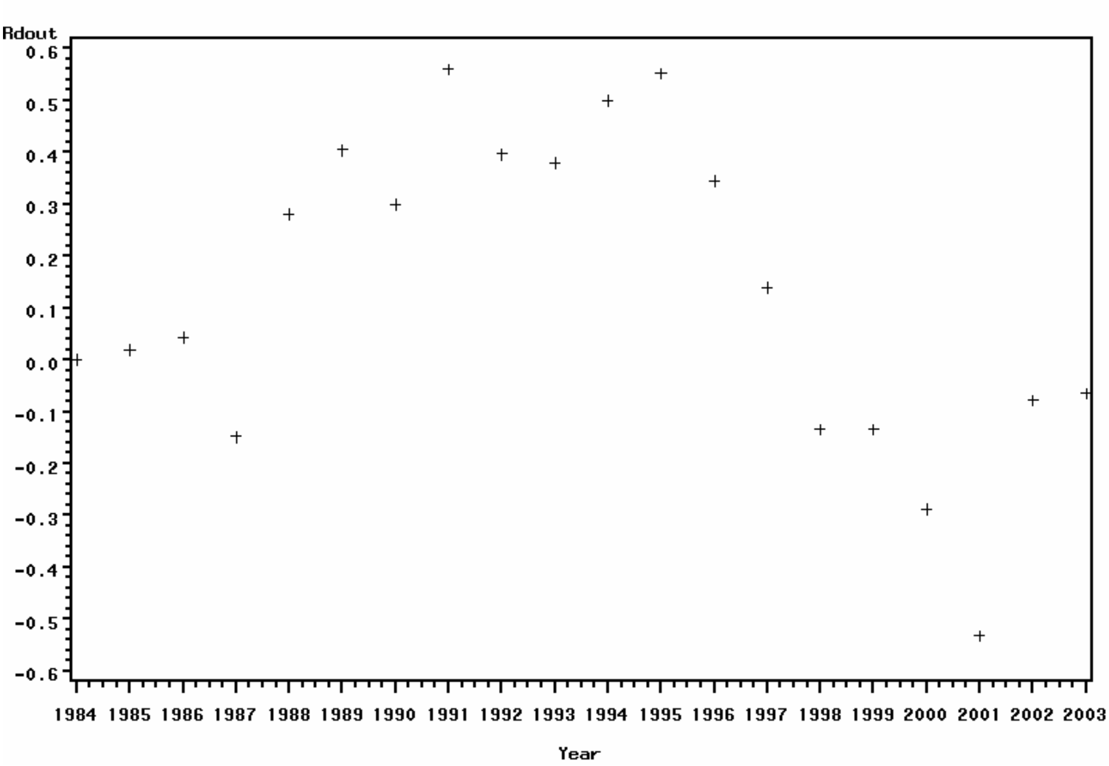


**Figure 15-10 Time plot of the Knowledge creation rate per FTE**

From Figure 15-7 can be seen that the time plot can be best be described though the "trend" specification. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-19: SAS output for Phillips Perron test for variable "Rdout"**

```
The ARIMA Procedure

Name of Variable = Rdout

Mean of Working Series      0.1272
```

Standard Deviation 0.29628
Number of Observations 20

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -3.6847 | 0.1738 | -1.39 | 0.1475 |
| | 1 | -3.6518 | 0.1758 | -1.38 | 0.1491 |
| Single Mean | 0 | -4.3549 | 0.4612 | -1.46 | 0.5310 |
| | 1 | -4.3861 | 0.4576 | -1.47 | 0.5284 |
| Trend | 0 | -5.5918 | 0.7293 | -1.80 | 0.6669 |
| | 1 | -5.4777 | 0.7400 | -1.78 | 0.6740 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.6669` for $\ell = 0$ en

`Pr < Tau = 0.6740` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `RDout` has a unit root and is non-stationary.

### 15.3.2 Full time Staff (Experimental development research, non contract)

The following is the time plot output from the SAS program for the FTE people in the system doing Basic and Applied research. The variable is the FTE R&D staff multiplied with the % time they are spending on basic and applied research and the % of funding spent on non-contract related R&D activities.

$$ftepattypestate = \ln\left(\frac{S_{FTE}}{S^*_{FTE}} * \frac{A_{ExpDev}}{A^*_{ExpDev}} * \frac{A_{Statet}}{A^*_{State}}\right)$$

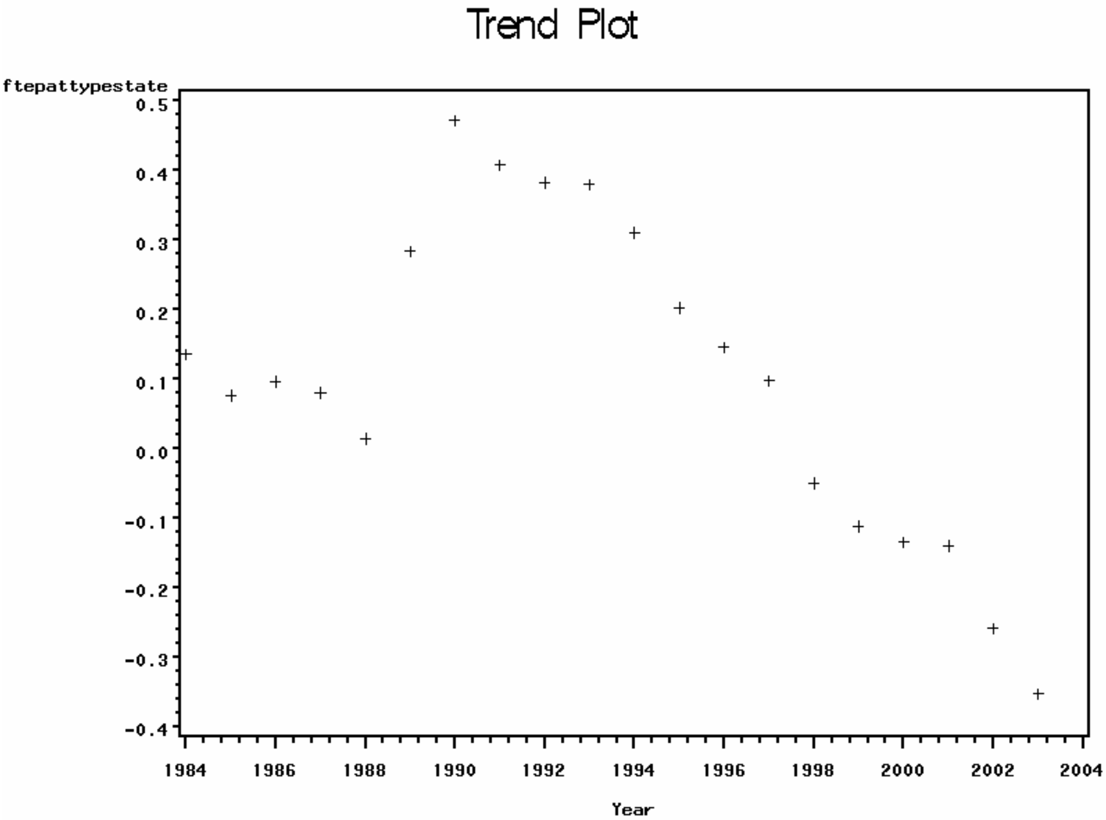


**Figure 15-11 Time plot - Absorbed knowledge stock per HC personnel**

From **Error! Reference source not found.** can be seen that the time plot shows an upward trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 15-20: SAS output for Phillips Perron test for variable "ftepattypestate"**

The ARIMA Procedure

Name of Variable = ftepattypestate

| | |
|---|---|
| Mean of Working Series | 0.1021 |
| Standard Deviation | 0.224336 |
| Number of Observations | 20 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -0.7501 | 0.5096 | -0.40 | 0.5242 |
| | 1 | -1.3614 | 0.4062 | -0.63 | 0.4303 |
| Single Mean | 0 | 0.4480 | 0.9666 | 0.20 | 0.9654 |
| | 1 | -0.2294 | 0.9328 | -0.11 | 0.9356 |
| Trend | 0 | -1.9198 | 0.9619 | -0.82 | 0.9450 |
| | 1 | -2.3734 | 0.9476 | -0.95 | 0.9287 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

Pr < Tau = 0.9450 for $\ell = 0$ en

Pr < Tau = 0.9287 for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that ftepattypestate has a unit root and is non-stationary.

### 15.3.3 Colinearity tests

First however we should make sure that the variables are not collinear. The following is the test results obtained from SAS for the Colinearity test.

**Table 15-21: Colinearity diagnostics for the model variables**

Collinearity Diagnostics

| Number | Eigenvalue | Condition Index | ----Proportion of Variation-- Intercept | ftepattypestate |
|---|---|---|---|---|
| 1 | 1.41424 | 1.00000 | 0.29288 | 0.29288 |
| 2 | 0.58576 | 1.55382 | 0.70712 | 0.70712 |

Larger values suggest potential near colinearity. Belsley, Kuh and Welsch (2000) recommend interpreting the Condition index greater or equal than 30 to reflect moderate to severe colinearity, worthy of further investigation. Since all the Condition indexes from the regression model is much smaller than 30, the conclusion can be made that colinearity is not a problem in this case.

***Proportion of Variation***

The variance proportion indicates for each predictor the proportion of total variance of its estimated regression coefficients associated with a particular principal component. The variance proportions suggest colinearity problems if more than one predictor has a high variance proportions of at least 0.5 for such a components suggest a problem. One should definitely be concerned when two or more ladings greater than 0.9 appear on a component with a large condition index (>30). This also does not seem to be a problem since the condition indexes are all small values.

### 15.3.4 Model estimation the rate of Patent Development in the PubS

As both variables entered in the model to be estimated are non-stationary, we should fit a model and then test for cointegration in the residual.

**Table 15-22: SAS code for the model estimation procedure**

```
proc reg data= Pub.patloglinear;
model Rdout = ftepattypestate
/ collin spec;
run;

/* r=0.60 p 0.00001  */
proc autoreg data= Pub.patloglinear;
model Rdout = ftepattypestate
/ dwprob method= ml archtest ;
output out=b r=residual;
run;
proc gplot data=b;
plot residual*year;
run;

proc arima data=b;
identify var=residual
stationarity=(phillips=(0,1));
run;
```

**Table 15-23: SAS output for the model estimation of Absorptive capacity in the HES**

```
                              The REG Procedure
                                Model: MODEL1
                          Dependent Variable: Rdout

                   Number of Observations Read          20
                   Number of Observations Used          20

                            Analysis of Variance

                                        Sum of           Mean
Source                   DF          Squares         Square    F Value    Pr > F

Model                     1          1.05369        1.05369      27.02    <.0001
Error                    18          0.70194        0.03900
Corrected Total          19          1.75563

             Root MSE              0.19748    R-Square     0.6002
             Dependent Mean        0.12720    Adj R-Sq     0.5780
             Coeff Var           155.24845

                            Parameter Estimates

                                        Parameter       Standard
  Variable              DF          Estimate          Error    t Value    Pr > |t|
```

```
               Intercept          1       0.02274       0.04852       0.47      0.6450
               ftepattypestate    1       1.02316       0.19683       5.20      <.0001


                                     The REG Procedure
                                      Model: MODEL1
                                 Dependent Variable: Rdout

                                  Test of First and Second
                                    Moment Specification

                                 DF    Chi-Square    Pr > ChiSq

                                  2          2.11        0.3488

                                  The AUTOREG Procedure

                                Dependent Variable    Rdout

                              Ordinary Least Squares Estimates

                     SSE                 0.70194207    DFE                       18
                     MSE                    0.03900    Root MSE             0.19748
                     SBC                 -4.2437275    AIC               -6.2351921
                     Regress R-Square        0.6002    Total R-Square        0.6002
                     Durbin-Watson           1.5178    Pr < DW               0.0875
                     Pr > DW                 0.9125
   NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-
   value for testing negative autocorrelation.

                            Q and LM Tests for ARCH Disturbances

                         Order          Q     Pr > Q          LM     Pr > LM

                           1       0.0215     0.8834      0.0320      0.8580
                           2       0.1960     0.9067      0.0802      0.9607
                           3       0.9652     0.8097      0.5220      0.9140
                           4       2.5316     0.6390      2.3069      0.6795
                           5       2.5335     0.7714      2.4582      0.7828
                           6       4.7339     0.5784      5.5867      0.4710
                           7       5.0327     0.6560      5.7859      0.5650
                           8       5.3684     0.7176      7.9828      0.4352
                           9       6.8896     0.6486     10.8254      0.2879
                          10       8.3899     0.5908     11.1950      0.3425
                          11       8.4369     0.6737     12.4735      0.3291
                          12       9.1364     0.6912     12.4735      0.4084

                                                          Standard                Approx
              Variable             DF       Estimate         Error    t Value    Pr > |t|

              Intercept             1         0.0227        0.0485       0.47      0.6450
              ftepattypestate       1         1.0232        0.1968       5.20      <.0001
```

From the model estimation output obtained we can make the following conclusion:

The **R-Square 0.6002** statistic indicate that the model accounts for 60% of the variation of the papers produced in the Public sector.

The test for autocorrelation use is the Durban Watson test statistic. The Durbin Watson test statistic is **1.9593 with** (Pr < DW = 0.0875 > 0.05 and (Pr < DW = 0.9125) < 0.95. This indicates that we therefore can conclude that the autoregressive model does not have autocorrelation.

The Chi-square test for the first moment specification indicates that the model does not have heteroscedastic errors. The SPEC option performs a model specification test. The null hypothesis for this test maintains that the errors are homoscedastic, independent of the regressor and that several technical assumptions about the model specification are valid. With Pr = 0.3488 we fail to reject the null hypothesis. We can therefore conclude that no heteroscedasiticity is present in the model.

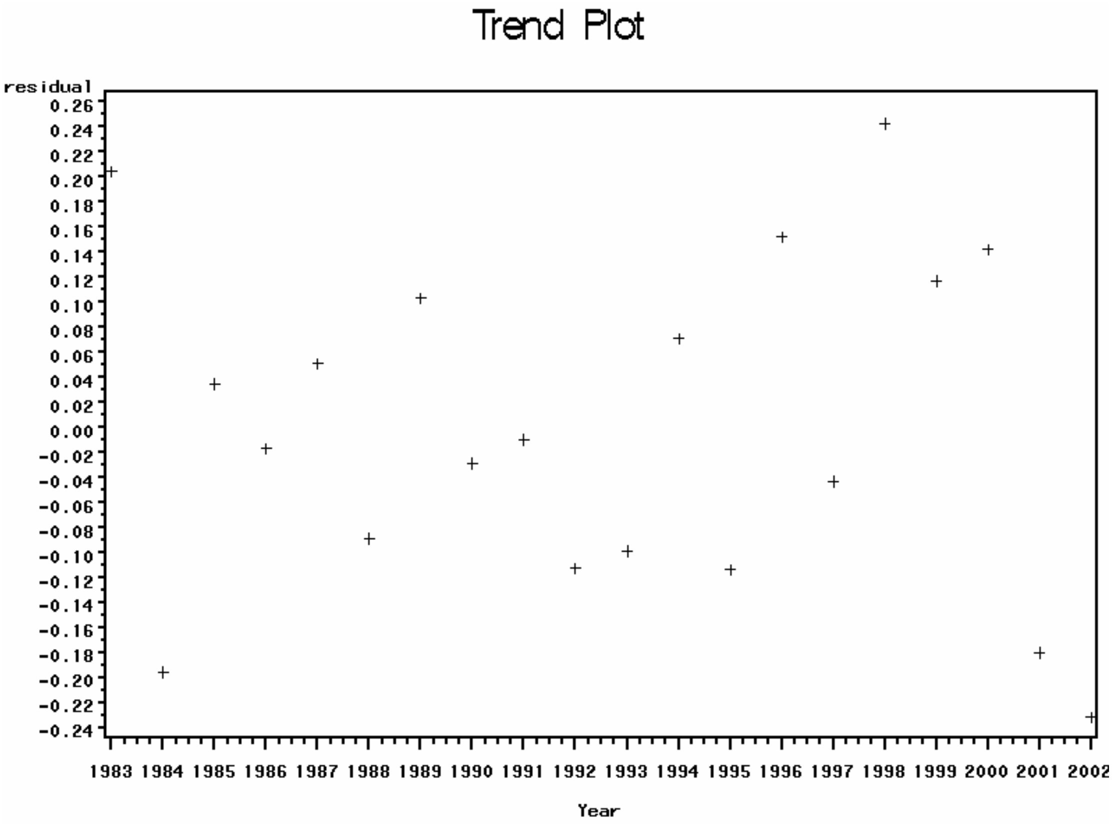


**Figure 15-12 Trend plot for the residual**

From Figure 15-12 can be seen that the time plot seems to be scattered around 0. From the results we van also read the `Mean of Working Series is -382E-19` in Table 15-24. We therefore make use of the "Zero mean" specification in the stationarity test output results.

**Table 15-24: SAS output for residual stationarity test**

```
                        The ARIMA Procedure

                    Name of Variable = residual

                  Mean of Working Series     -382E-19
                  Standard Deviation         0.187342
                  Number of Observations           20

                   Phillips-Perron Unit Root Tests

 Type            Lags     Rho          Pr < Rho      Tau       Pr < Tau

Zero Mean          0     -15.4024      0.0019       -3.37      0.0019
                   1     -15.7512      0.0016       -3.39      0.0019
Single Mean        0     -15.3087      0.0112       -3.25      0.0325
                   1     -15.6218      0.0098       -3.27      0.0313
Trend              0     -15.3592      0.0695       -3.17      0.1191
                   1     -15.7363      0.0611       -3.20      0.1144
```

For (n-1) = 1, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See table Table 15-24). The critical value for the 5% level is -3.37.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Tau = -3.37` for $\ell = 0$ en

`Tau = -3.39` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root with a 5% significance level, since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

# 16 APPENDIX E

## 16.1 Absorption of Knowledge (Private sector)

The rate at which the system is able to produce new knowledge output is computed through the contribution made form different stocks in the system. The following expression is formulated for the R&D knowledge absorption rate in the system:

- $R_{Absorptionr}$ : Absorption rate of knowledge in the system
- $S_{R\&Doutput} * S_{FTE}$ : RD output stock interacting with the presence of people full time equivalent people who can draw on the stocks of knowledge person in system
- $S_{World} / S_{HC}$ : Available external knowledge stock per Headcount personnel employed in the system

A multiplicative model is developed for the absorption rate per full time person working in the system:

$$\frac{R_{Absorptionr}}{R^*_{Absorption}} = f * \left(\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}}\right)^d * \left(\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}}\right)^e \qquad \textbf{16-1}$$

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Absorptionr}}{R^*_{Absorption}}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S^*_{R\&Doutpu}} * \frac{S_{FTE}}{S^*_{FTE}}\right) + e * \ln\left(\frac{S_{World}}{S^*_{World}} / \frac{S_{HC}}{S^*_{HC}}\right)$$

**16-2**

This is the expression used to perform the regression for estimating the parameters $d$ , $e$ and $f$ .

The section describes the variables included in the model to estimate the rate of knowledge absorption in the system. The following SAS program was used.

**Table 16-1: SAS code for stationarity tests in variables AbsorbedR, RDfte and wsperhc**

```
goptions reset=all cback=white colors=(black) lfactor=2
border;
title1 'Trend Plot';
proc gplotb data = priv.loglin;
plot (arperfte rdfte wsperhc)*year;
plot arperfte *(rdfte wsperhc);
run;

* test for stationarity of the 3 series using arima procedure
*;
proc arima data=priv.loglin;
identify var= arperfte stationarity=(phillips=(0,1));
identify var=rdfte stationarity=(phillips=(0,1));
identify var=wsperhc stationarity=(phillips=(0,1));
```

```
run;
```

The following sections document and explain the output obtained from the SAS program.

### 16.1.1 Absorption rate of knowledge in the system

The following is the time plot output from the SAS program for the absorption rate per full time equivalent researchers in the system.

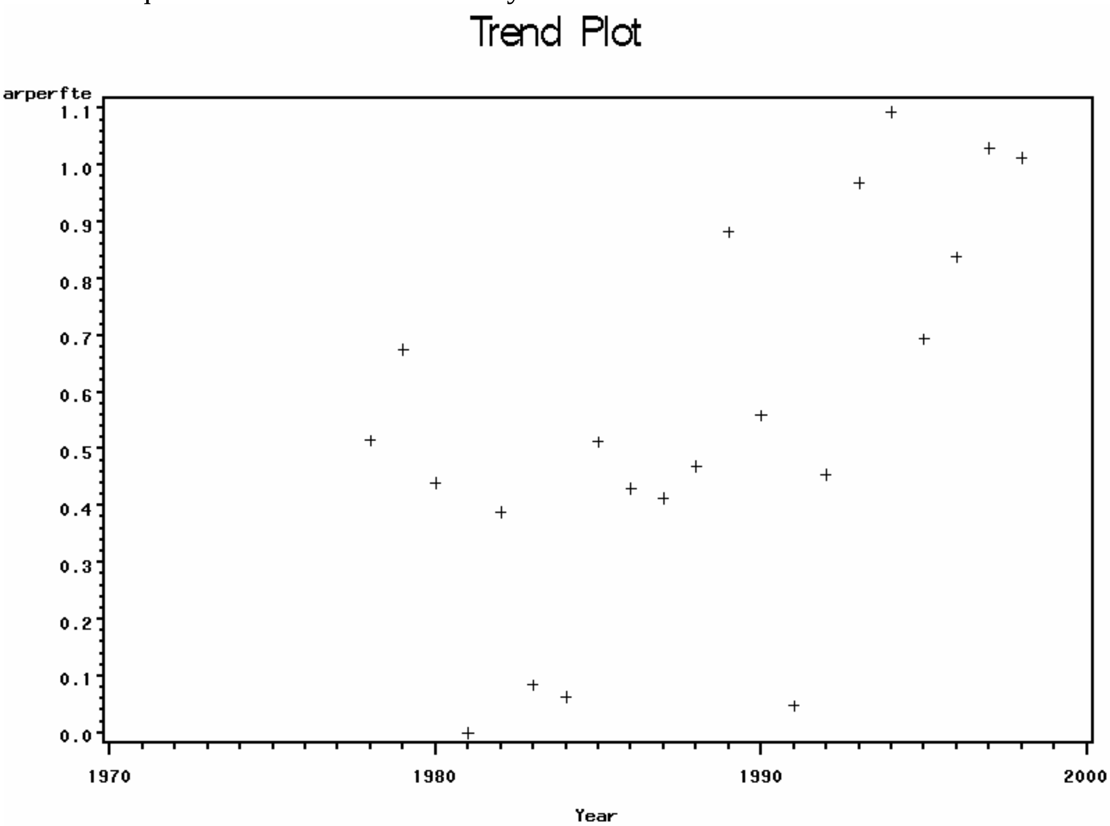


**Figure 16-1 Time plot of the absorption rate in the Private sector**

From **Error! Reference source not found.** can be seen that the time plot shows an upward trend. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 16-2: Phillips-Perron test output for variable "`arperfte`"**

```
The ARIMA Procedure

Name of Variable = arperfte

Mean of Working Series     0.503147
Standard Deviation         0.329908
Number of Observations           21

The ARIMA Procedure

Phillips-Perron Unit Root Tests
```

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -1.7376 | 0.3537 | -0.66 | 0.4172 |

| | | | | | |
|---|---|---|---|---|---|
| | 1 | -1.7138 | 0.3569 | -0.65 | 0.4202 |
| Single Mean | 0 | -10.6238 | 0.0704 | -2.53 | 0.1233 |
| | 1 | -11.7998 | 0.0468 | -2.64 | 0.1021 |
| Trend | 0 | -15.7939 | 0.0658 | -3.32 | 0.0921 |
| | 1 | -17.2017 | 0.0401 | -3.40 | 0.0800 |

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.0921` for $\ell = 0$ en

`Pr < Tau = 0.0800` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `arperfte` has a unit root and is non-stationary.

### 16.1.2 R&D Knowledge Stock and FTE researchers interaction

The following is the time plot output from the SAS program for the RD Knowledge stock with Full time equivalent personnel in the system.

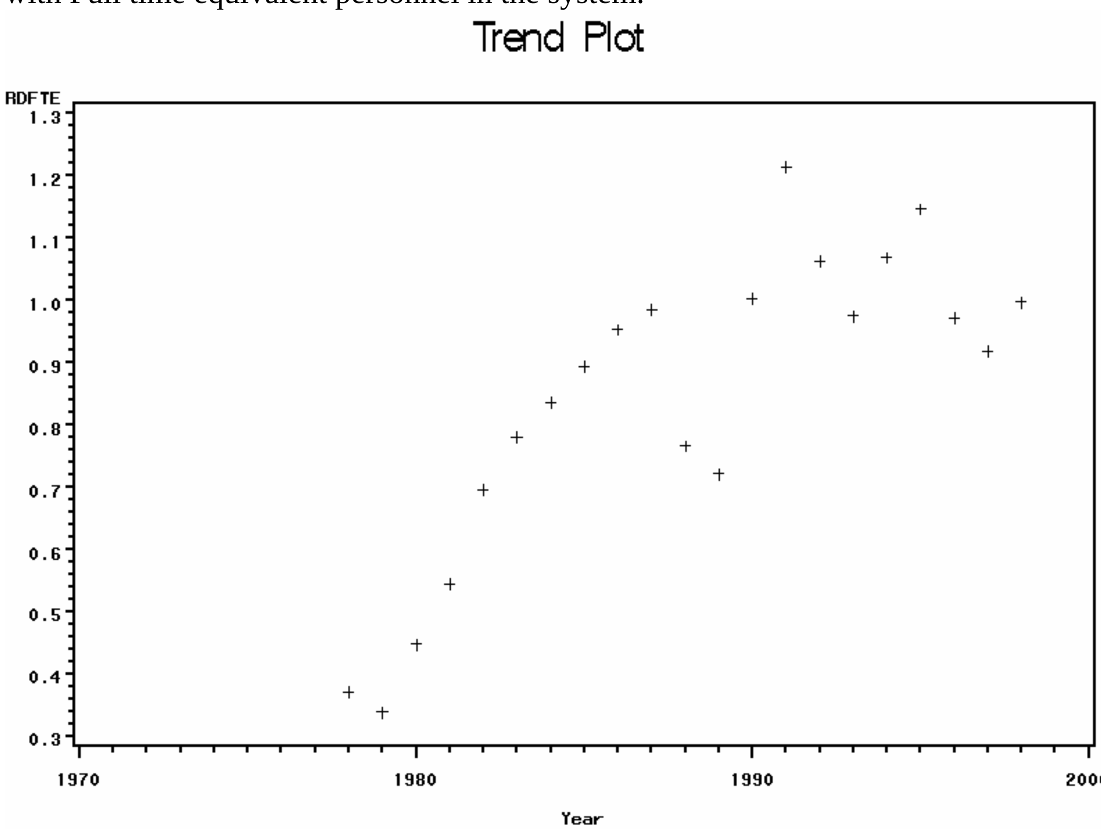


**Figure 16-2 Time plot - FTE researcher interacting with R&D knowledge**

From Figure 16-2 can be seen that the time plot shows an upward trend. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 16-3: Phillips-Perron test output for variable "`RDFTE`"**

```
                    The ARIMA Procedure

                 Name of Variable = RDFTE

           Mean of Working Series    0.604104
           Standard Deviation         0.24815
           Number of Observations          21

                 Phillips-Perron Unit Root Tests

Type          Lags       Rho     Pr < Rho       Tau    Pr < Tau

Zero Mean        0    0.1144       0.6971      0.12      0.7093
                 1    0.0630       0.6844      0.06      0.6908
Single Mean      0   -5.6262       0.3308     -2.73      0.0860
                 1   -5.8495       0.3108     -2.69      0.0923
Trend            0   -8.7810       0.4304     -2.23      0.4476
                 1   -9.9789       0.3331     -2.36      0.3874
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.4476` for $\ell = 0$ en

`Pr < Tau = 0.3874` for $\ell = 1$.

Both $p$-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `RDFTE` has a unit root and is non-stationary.

### 16.1.3 The external knowledge stock

The following is the time plot output from the SAS program for the World Knowledge Stock per Headcount person employed in the Higher Education system.

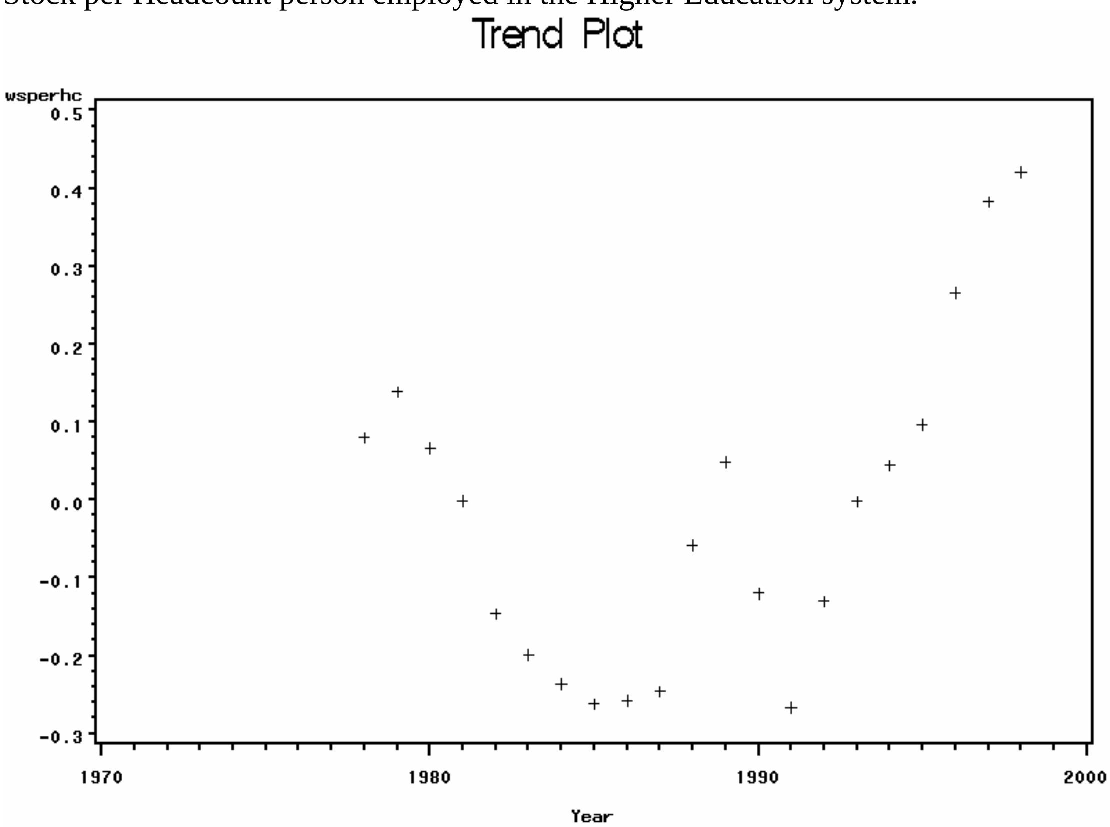

**Figure 16-3 Time plot - World stock of knowledge per HC researcher**

From **Error! Reference source not found.** can be seen that the time plot shows an upward trend. We therefore make use of the “Trend” specification in the stationarity test output results.

**Table 16-4: Phillips-Perron test output for variable “WSperHC”**

```
                        The ARIMA Procedure

                  Name of Variable = wsperhc

                Mean of Working Series    -0.03798
                Standard Deviation        0.175669
                Number of Observations          21

                 Phillips-Perron Unit Root Tests

Type            Lags        Rho     Pr < Rho        Tau     Pr < Tau
Zero Mean          0    -1.4766       0.3903      -0.50       0.4856
                   1    -3.2016       0.2061      -0.92       0.3043
Single Mean        0    -0.7238       0.8970      -0.22       0.9204
                   1    -2.6069       0.6844      -0.71       0.8227
Trend              0    -1.2211       0.9791      -0.40       0.9797
                   1    -2.3452       0.9505      -0.71       0.9583
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.9797` for $\ell = 0$ en

`Pr < Tau = 0.9583` for $\ell = 1$.

Both $p$-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `wsperhc` has a unit root and is non-stationary.

### 16.1.4 Colinearity tests

First however we should make sure that the variables are not collinear. The following is the test results obtained from SAS for the Colinearity test.

**Table 16-5: Colinearity diagnostics for the model variables**

```
                    Collinearity Diagnostics

                                       Condition
       Number     Eigenvalue           Index
          1         2.04882            1.00000
          2         0.88054            1.52538
          3         0.07064            5.38552

                  ---------Proportion of Variation---------
   Number        Intercept          RDFTE        wsperhc
     1           0.02987             0.02973        0.04556
     2           0.01250             0.00486        0.89138
     3           0.95763             0.96540        0.06306
```

Larger values suggest potential near colinearity. Belsley, Kuh and Welsch (2000) recommend interpreting the Condition index greater or equal than 30 to reflect moderate to severe colinearity, worthy of further investigation. Since all the Condition indexes from the regression model are much smaller than 30, the conclusion can be made that colinearity is not a problem in this case.

***Proportion of Variation***

The variance proportion indicates for each predictor the proportion of total variance of its estimated regression coefficients associated with a particular principal component. The variance proportions suggest colinearity problems if more than one predictor has a high variance proportions of at least 0.5 for such a components suggest a problem. One should definitely be concerned when two or more ladings greater than 0.9 appear on a component with a large condition index (>30). This also does not seem to be a problem since the condition indexes are all smaller than 30.

### 16.1.5 Model estimation - Absorption rate

As all three variables are non-stationary, we should now fit a model and then test for cointegration in the residual.

**Table 16-6: SAS code for the model estimation procedure**

```
proc autoreg data=Priv.loglinear ;
model arperfte = RDFTe wsperhc
/ method=ml dwprob stationarity=(phillips=(1));
output out=abspriv r=residual;
run;
```

**Table 16-7: SAS output for the model estimation of Absorptive capacity in the HES**

```
                          The AUTOREG Procedure

                      Dependent Variable    arperfte


                     Ordinary Least Squares Estimates

       SSE                   0.96423696    DFE                       18
       MSE                      0.05357    Root MSE             0.23145
       SBC                   4.02923226    AIC               0.89566494
       Regress R-Square          0.5781    Total R-Square        0.5781
       Durbin-Watson             1.7635    Pr < DW               0.1533
       Pr > DW                   0.8467
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                 Q and LM Tests for ARCH Disturbances

        Order          Q    Pr > Q          LM    Pr > LM

          1       0.2084    0.6481      0.1093     0.7409
          2       1.3994    0.4967      1.4322     0.4887
          3       3.5987    0.3082      2.3405     0.5048
          4       7.0608    0.1327     10.3345     0.0352
          5       7.7103    0.1729     10.4443     0.0636
          6       8.4556    0.2066     11.4023     0.0767
          7       9.8622    0.1965     11.4473     0.1203
          8      10.0637    0.2606     13.2544     0.1034
          9      10.2928    0.3273     14.3887     0.1092
         10      10.4760    0.3998     17.8694     0.0572
         11      11.6565    0.3900     18.3951     0.0729
         12      12.1879    0.4307     19.1378     0.0853
```

```
                        Phillips-Ouliaris
                        Cointegration Test

                 Lags            Rho           Tau

                    1       -18.6489       -4.0045


                                            Standard                 Approx
 Variable         DF       Estimate          Error     t Value     Pr > |t|

 Intercept         1         0.1729         0.1351        1.28       0.2168
 RDFTE             1         0.6339         0.2117        2.99       0.0078
 wsperhc           1         1.3863         0.2991        4.63       0.0002

                     The AUTOREG Procedure

                 Dependent Variable    arperfte


                 Ordinary Least Squares Estimates

    SSE                  0.96423696    DFE                       18
    MSE                     0.05357    Root MSE             0.23145
    SBC                  4.02923226    AIC               0.89566494
    Regress R-Square         0.5781    Total R-Square        0.5781
    Durbin-Watson            1.7635    Pr < DW               0.1533
    Pr > DW                  0.8467
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-value
for testing negative autocorrelation.

                        Phillips-Ouliaris
                        Cointegration Test

                 Lags            Rho           Tau

                    1       -18.6489       -4.0045


                                            Standard                 Approx
 Variable         DF       Estimate          Error     t Value     Pr > |t|

 Intercept         1         0.1729         0.1351        1.28       0.2168
 RDFTE             1         0.6339         0.2117        2.99       0.0078
 wsperhc           1         1.3863         0.2991        4.63       0.0002
```

From the model estimation output obtained we can make the following conclusion:

The test for autocorrelation use is the Durban Watson test statistic. The `Durbin Watson` test statistic is `1.7635 with (Pr < DW = 0.1533) > 0.05 and (Pr < DW = 0.8467) < 0.95`. This indicates that we can we therefore can conclude that the autoregressive model does not have autocorrelation.

The heteroscedasticity test (Q and LM test for ARCH disturbances) is only interpreted up to 2 time lags. The probability for arch disturbances in the model for lags 1 and 2 are larger than 0.05. We can therefore conclude that the modelled relationship does not suffer from heteroscedasticity.

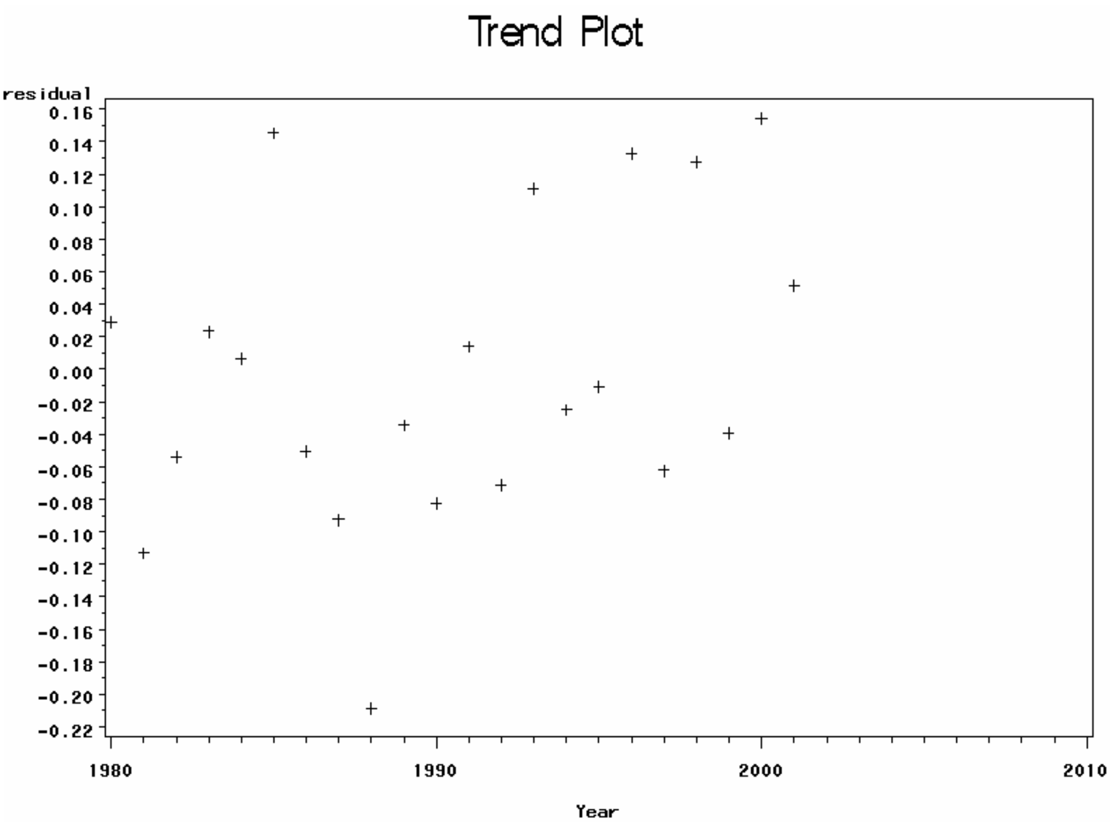


**Figure 16-4 Time plot for the residual of the knowledge absorption model**

From Figure 16-5 can be seen that the time plot seems to be scattered around 0. From the results we van also read the `Mean of Working Series -0.00219` in Table 16-8: . We therefore make use of the "Zero mean" specification in the stationarity test output results.

**Table 16-8: Stationarity test for the residual**

The ARIMA Procedure

Name of Variable = residual

| | |
|---|---|
| Mean of Working Series | -889E-19 |
| Standard Deviation | 0.21428 |
| Number of Observations | 21 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -18.0392 | 0.0006 | -3.99 | 0.0004 |
| | 1 | -18.6489 | 0.0004 | -4.00 | 0.0004 |
| Single Mean | 0 | -18.0573 | 0.0037 | -3.89 | 0.0084 |
| | 1 | -18.6569 | 0.0028 | -3.91 | 0.0081 |
| Trend | 0 | -18.0173 | 0.0296 | -3.75 | 0.0424 |
| | 1 | -18.6237 | 0.0233 | -3.77 | 0.0407 |

Since an intercept is included in the model fitted, an intercept is included. For (n-1) = 2, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See Table 16-8: ). The critical value for the 5% level is -3.77.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.
`Tau = -3.99` for $\ell = 0$ en
`Tau = -4.00` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

## 16.2 Creation of new knowledge (Private sector)

The rate at which the system is able to produce new knowledge output is computed through the contribution made form different stocks in the system. The following expression is formulated for the R&D output productivity per FTE researcher working in the system:

- $R_{Paper} / S_{FTE}$ : R&D output rate per FTE researcher person on the system
- $S_{Experience} / S_{HC}$ : Average Experience Stock of the people in the system.
- $S_{Absorbed} / S_{HC}$ : Average Absorbed knowledge per person in the system.

A multiplicative model is developed for the development rate of papers per full time person working in the system:

$$\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}} = c * \left(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}\right)^a * \left(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}\right)^b \quad \textbf{16-3}$$

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Paper}}{R^*_{Paper}} / \frac{S_{FTE}}{S^*_{FTE}}\right) = \ln(c) + a * \ln\left(\frac{S_{Experience}}{S^*_{Experience}} / \frac{S_{HC}}{S^*_{HC}}\right) + b * \ln\left(\frac{S_{Absorbed}}{S^*_{Absorbed}} / \frac{S_{HC}}{S^*_{HC}}\right)$$

**16-4**

This is then the expression used to perform the regression for estimating the parameters $a$, $b$ and $c$.

The section describes the variables included in the model to estimate the rate of knowledge creation in the system. The following SAS program was used.

**Table 16-9: SAS code for the stationarity tests procedure for “prperfte”, “ftetot”, “AbsS”**

```
goptions reset=all cback=white colors=(black) lfactor=2
border;
title1 'Trend Plot';
proc gplot priv.loglin;
plot (prperfte ftetot AbsS)*year;
plot prperfte*(ftetot AbsS);
run;

* test for stationarity of the 3 series using arima procedure
*;
proc arima priv.loglin;
identify var=prperfte stationarity=(phillips=(0,1));
identify var=ftetot stationarity=(phillips=(0,1));
identify var=AbsS stationarity=(phillips=(0,1));
run;
```

The following sections document and explain the output obtained from the SAS program.

### 16.2.1 R&D output produced per FTE researcher

The following is the time plot output from the SAS program for the R&D output (papers) created per full time equivalent researcher in the system.

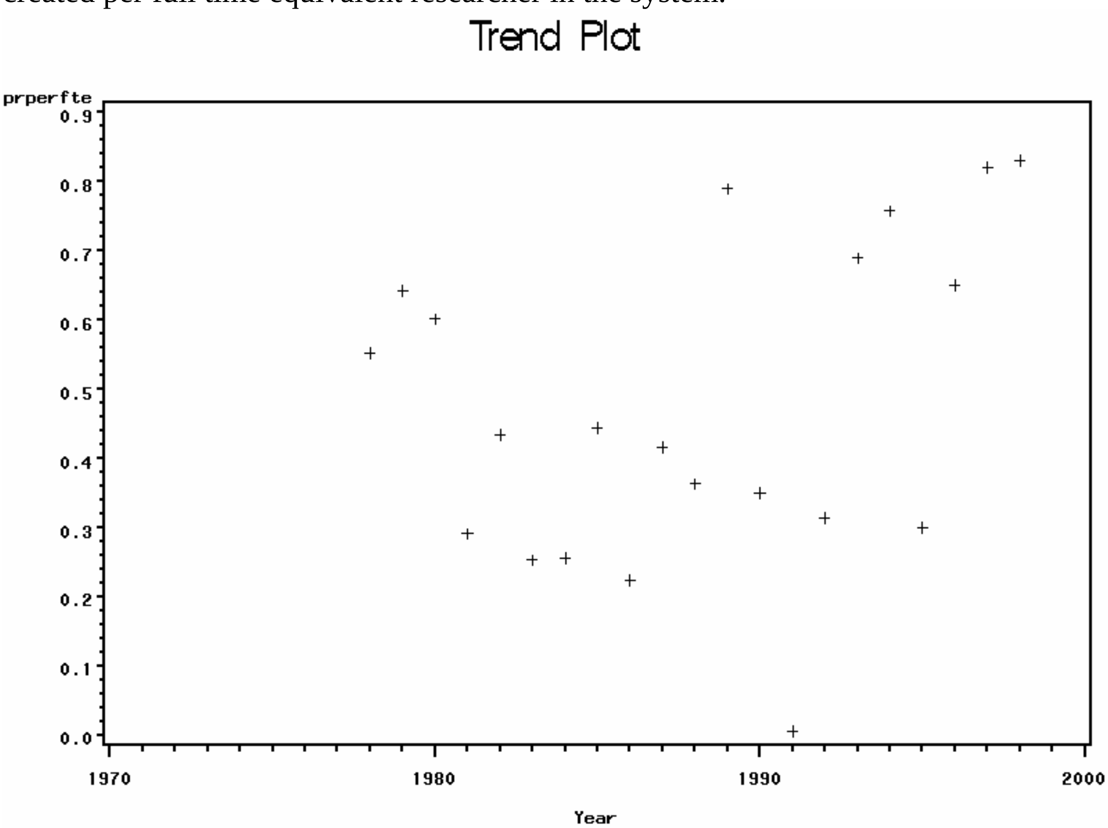


**Figure 16-5 Time plot of the Knowledge creation rate per FTE**

From Figure 16-5 can be seen that the time plot although scattered seems to follow an upward trend. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 16-10: SAS output for Phillips Perron test for variable "prperfte"**

```
                         The ARIMA Procedure

                       Name of Variable = prperfte

                    Mean of Working Series    0.475973
                    Standard Deviation         0.22445
                    Number of Observations          21

                        Phillips-Perron Unit Root Tests

     Type            Lags         Rho     Pr < Rho        Tau     Pr < Tau

     Zero Mean          0     -1.9449       0.3271      -0.83       0.3434
                        1     -1.5327       0.3821      -0.71       0.3965
     Single Mean        0    -13.5207       0.0249      -2.82       0.0725
                        1    -14.1240       0.0197      -2.87       0.0660
     Trend              0    -14.7705       0.0918      -3.10       0.1331
                        1    -14.7723       0.0918      -3.10       0.1331
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.1331` for $\ell = 0$ en

`Pr < Tau = 0.1331` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `rdperfte` has a unit root and is non-stationary.

### 16.2.2 Absorbed Stock

The following is the time plot output from the SAS program for the Absorbed knowledge stock in the system.

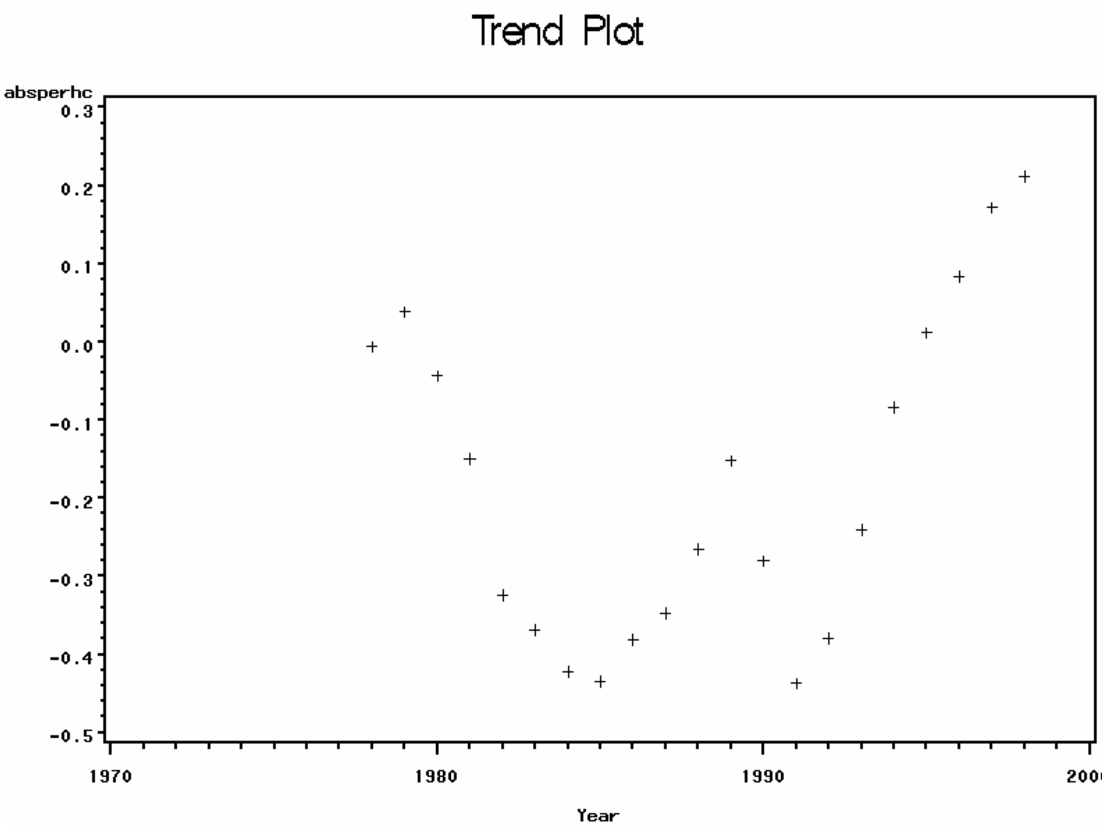


**Figure 16-6 Time plot of the Absorbed knowledge stock per HC personnel**

From **Error! Reference source not found.** can be seen that the time plot shows a trend line. We therefore make use of the "Trend" specification in the stationarity test output results.

**Table 16-11: SAS output for Phillips Perron test for variable "Absperhc"**

Name of Variable = absperhc

| | |
|---|---|
| Mean of Working Series | -0.18065 |
| Standard Deviation | 0.203145 |
| Number of Observations | 21 |

Phillips-Perron Unit Root Tests

| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau |
|---|---|---|---|---|---|
| Zero Mean | 0 | -0.9679 | 0.4709 | -0.60 | 0.4439 |
| | 1 | -1.6692 | 0.3630 | -0.83 | 0.3422 |
| Single Mean | 0 | -0.8287 | 0.8880 | -0.34 | 0.9020 |
| | 1 | -2.3245 | 0.7208 | -0.79 | 0.7998 |
| Trend | 0 | -1.9274 | 0.9634 | -0.91 | 0.9346 |
| | 1 | -2.5355 | 0.9435 | -1.07 | 0.9102 |

From the Phillips Perron test output obtained from SAS we read the following values for

the probability statistics.
`Pr < Tau = 0.9346` for $\ell$ = 0 en
`Pr < Tau = 0.9102` for $\ell$ = 1.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d$ = 1. We have to conclude that `absperhc` has a unit root and is non-stationary.

### 16.2.3 Experience per Headcount in the system

The following is the time plot output from the SAS program for the Full time personnel in the system.

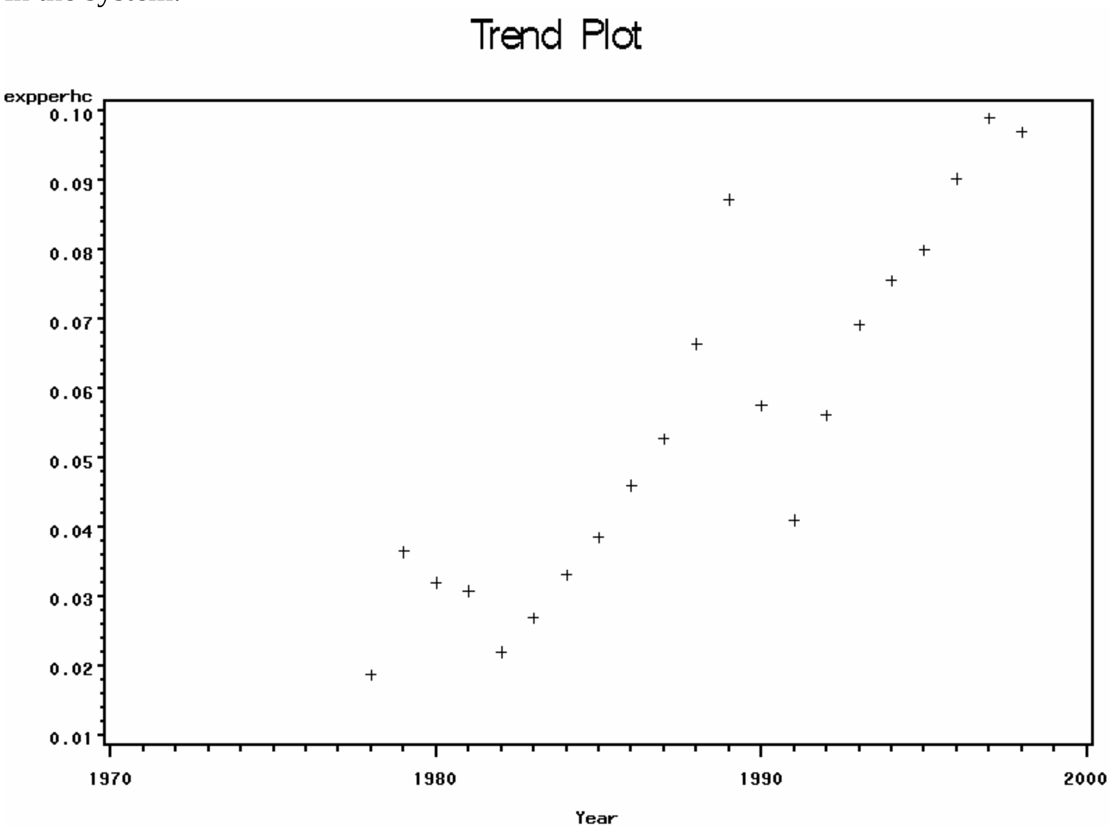


**Figure 16-7 Time plot for the “Expperhc” variable in the system**

From Figure 16-7 can be seen that the time plot shows an downward trend line. We therefore make use of the “Trend” specification in the stationarity test output results.

**Table 16-12: SAS output for Phillips Perron test for variable “Expperhc”**

```
                   Name of Variable = expperhc

                 Mean of Working Series      0.0551
                 Standard Deviation        0.024941
                 Number of Observations          21

                    Phillips-Perron Unit Root Tests

Type            Lags          Rho     Pr < Rho          Tau     Pr < Tau

Zero Mean          0       0.8955       0.8770         0.94       0.9011
                   1       0.8630       0.8710         0.87       0.8902
Single Mean        0      -2.0219       0.7589        -0.89       0.7699
                   1      -2.3803       0.7137        -0.98       0.7387
Trend              0     -10.7197       0.2812        -2.48       0.3342
                   1     -12.4559       0.1811        -2.64       0.2693
```

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Pr < Tau = 0.3342` for $\ell = 0$ en

`Pr < Tau = 0.2693` for $\ell = 1$.

Both *p*-values are greater than 0.05. We therefore cannot reject $H_0$: $d = 1$. We have to conclude that `Expperhc` has a unit root and therefore is non-stationary.

### 16.2.4 Colinearity tests

First however we should make sure that the variables are not collinear. The following is the test results obtained from SAS for the Colinearity test.

**Figure 16-8 Colinearity diagnostics for the model variables**

```
           Collinearity Diagnostics

                                Condition
Number      Eigenvalue          Index
   1         2.36140            1.00000
   2         0.59053            1.99969
   3         0.04807            7.00918

            ---------Proportion of Variation---------
 Number       Intercept       absperhc       Expperhc
    1         0.01425         0.04170        0.01752
    2         0.00357         0.46016        0.05796
    3         0.98218         0.49814        0.92452
```

Larger values suggest potential near colinearity. Belsley, Kuh and Welsch (2000) recommend interpreting the Condition index greater or equal than 30 to reflect moderate to severe colinearity, worthy of further investigation. Since all the Condition indexes from the regression model is much smaller than 30, the conclusion can be made that colinearity is not a problem in this case.

***Proportion of Variation***

The variance proportion indicates for each predictor the proportion of total variance of its estimated regression coefficients associated with a particular principal component. The variance proportions suggest colinearity problems if more than one predictor has a high variance proportions of at least 0.5 for such a components suggest a problem. One should definitely be concerned when two or more ladings greater than 0.9 appear on a component with a large condition index (>30). This also does not seem to be a problem since the condition indexes are all small values.

### 16.2.5 Model estimation the rate of Paper Development in the HES

As all three variables are non-stationary, we should now fit a model and then test for cointegration in the residual

**Table 16-13: SAS code for the model estimation procedure**

```
proc autoreg data=Priv.loglinear ;
model prperfte = absperhc expperhc
/ method=ml dwprob  stationarity=(phillips=(1));
output out=abspriv r=residual;
run;

proc reg data = Priv.loglinear ;
    model prperfte = absperhc expperhc
    /tol vif collin spec dw;
    output out=abspriv r=residual;
run;

* consider residual *;
proc gplot data= abspriv;
plot residual*year;
run;

* test for cointegration using arima procedure *;
proc arima data=abspriv;
identify var=residual
stationarity=(phillips=(0,1));
run;
```

**Table 16-14: SAS output for the model estimation of patent output in the Private sector**

```
                          The AUTOREG Procedure

                    Dependent Variable    prperfte

                    Ordinary Least Squares Estimates

              SSE                   0.44599109    DFE                      18
              MSE                      0.02478    Root MSE            0.15741
              SBC                   -12.162568    AIC              -15.296135
              Regress R-Square          0.5784    Total R-Square       0.5784
              Durbin-Watson             2.3068    Pr < DW              0.5945
              Pr > DW                   0.4055
NOTE: Pr<DW is the p-value for testing positive autocorrelation, and Pr>DW is the p-
value for testing negative autocorrelation.
```

Q and LM Tests for ARCH Disturbances

| Order | Q | Pr > Q | LM | Pr > LM |
|---|---|---|---|---|
| 1 | 0.2084 | 0.6481 | 0.1093 | 0.7409 |
| 2 | 1.3994 | 0.4967 | 1.4322 | 0.4887 |
| 3 | 3.5987 | 0.3082 | 2.3405 | 0.5048 |
| 4 | 7.0608 | 0.1327 | 10.3345 | 0.0352 |
| 5 | 7.7103 | 0.1729 | 10.4443 | 0.0636 |
| 6 | 8.4556 | 0.2066 | 11.4023 | 0.0767 |
| 7 | 9.8622 | 0.1965 | 11.4473 | 0.1203 |
| 8 | 10.0637 | 0.2606 | 13.2544 | 0.1034 |
| 9 | 10.2928 | 0.3273 | 14.3887 | 0.1092 |
| 10 | 10.4760 | 0.3998 | 17.8694 | 0.0572 |
| 11 | 11.6565 | 0.3900 | 18.3951 | 0.0729 |
| 12 | 12.1879 | 0.4307 | 19.1378 | 0.0853 |

Phillips-Ouliaris
Cointegration Test

| Lags | Rho | Tau |
|---|---|---|
| 1 | -22.3665 | -5.1370 |

| Variable | DF | Estimate | Standard Error | t Value | Approx Pr > \|t\| |
|---|---|---|---|---|---|
| Intercept | 1 | 0.4779 | 0.1193 | 4.01 | 0.0008 |
| absperhc | 1 | 0.6672 | 0.2013 | 3.31 | 0.0039 |
| expperhc | 1 | 2.1522 | 1.6392 | 1.31 | 0.2057 |

Dependent Variable: prperfte

| | |
|---|---|
| Number of Observations Read | 21 |
| Number of Observations Used | 21 |

Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 2 | 0.61195 | 0.30597 | 12.35 | 0.0004 |
| Error | 18 | 0.44599 | 0.02478 | | |
| Corrected Total | 20 | 1.05794 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 0.15741 | R-Square | 0.5784 |
| Dependent Mean | 0.47597 | Adj R-Sq | 0.5316 |
| Coeff Var | 33.07080 | | |

Parameter Estimates

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| | Tolerance | Variance Inflation |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | 0.47791 | 0.11925 | 4.01 | 0.0008 | . | 0 |
| absperhc | 1 | 0.66715 | 0.20126 | 3.31 | 0.0039 | 0.70586 | 1.41671 |
| expperhc | 1 | 2.15218 | 1.63923 | 1.31 | 0.2057 | 0.70586 | 1.41671 |

Test of First and Second
Moment Specification

| DF | Chi-Square | Pr > ChiSq |
|---|---|---|
| 5 | 4.30 | 0.5076 |

From the model estimation output obtained we can make the following conclusion:

The **R-Square 0.5784** statistic indicate that the model accounts for 57% of the variation of the percentage time spent by staff on R&D activities.

The test for autocorrelation use is the Durban Watson test statistic. The `Durbin Watson` test statistic is `2.3068 with (Pr < DW = 0.6945 > 0.05 and (Pr < DW = 0.4055) < 0.95`. This indicates that we therefore can conclude that the autoregressive model does not have autocorrelation.

The heteroscedasticity test (Q and LM test for ARCH disturbances) is only interpreted up to 2 time lags. The probability for arch disturbances in the model for lags 1 and 2 are larger than 0.05. We can therefore conclude that the modelled relationship does not suffer from heteroscedasticity.

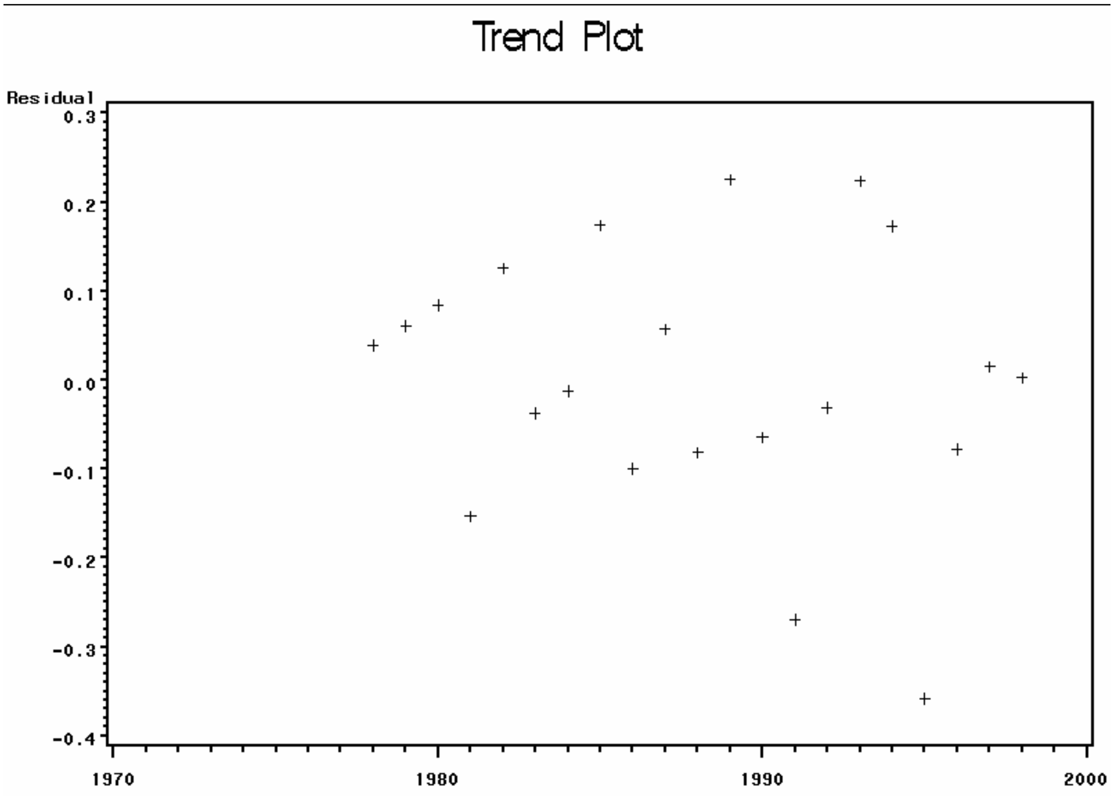


**Figure 16-9 Time plot of the residual**

From Figure 16-9 can be seen that the time plot seems to be scattered around 0. From the results we van also read the `Mean of Working Series is 8.02E-17` in **Error! Reference source not found.**. We therefore make use of the "Zero mean" specification in the stationarity test output results.

**Table 16-15: Stationarity tests output for the residual**

```
                    The ARIMA Procedure

                Name of Variable = residual

                Mean of Working Series    8.02E-17
                Standard Deviation        0.145732
                Number of Observations          21

                    Phillips-Perron Unit Root Tests

Type              Lags         Rho     Pr < Rho        Tau     Pr < Tau

Zero Mean            0    -23.1026       <.0001      -5.11       <.0001
                     1    -22.3665       <.0001      -5.14       <.0001
Single Mean          0    -23.1028       0.0003      -4.97       0.0008
                     1    -22.3618       0.0004      -5.00       0.0008
Trend                0    -23.7885       0.0022      -4.98       0.0039
                     1    -22.8581       0.0035      -5.02       0.0036
```

For (n-1) = 2, the values are obtained from the Critical values for the Phillips Z Statistic or the Dickey Fuller t Statistic when applied to Residuals from Spurious Cointegration Regression (See table **Error! Reference source not found.**). The critical value for the 1% level is -4.31.

From the Phillips Perron test output obtained from SAS we read the following values for the probability statistics.

`Tau = -5.11` for $\ell = 0$ en

`Tau = -5.14` for $\ell = 1$.

This means that we can therefore reject the null hypothesis of unit root with a 1% significance level, since the `Tau` values are smaller than the critical value. The residues can be deemed stationary and the variables are cointegrated. We can therefore conclude that the regression is not spurious.

# 17 STATISTICAL TABLES

**Table 17-1: Critical values for the Phillips Z statistic**

**TABLE B.9**
**Critical Values for the Phillips $Z_t$ Statistic or the Dickey-Fuller $t$ Statistic When Applied to Residuals from Spurious Cointegrating Regression**

| *Number of right-hand variables in regression, excluding trend or constant* | *Sample size* | *Probability that $(\hat{\rho} - 1)/\hat{\sigma}_{\hat{\rho}}$ is less than entry* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $(n - 1)$ | $(T)$ | *0.010* | *0.025* | *0.050* | *0.075* | *0.100* | *0.125* | *0.150* |
| | | | | *Case 1* | | | | |
| 1 | 500 | −3.39 | −3.05 | −2.76 | −2.58 | −2.45 | −2.35 | −2.26 |
| 2 | 500 | −3.84 | −3.55 | −3.27 | −3.11 | −2.99 | −2.88 | −2.79 |
| 3 | 500 | −4.30 | −3.99 | −3.74 | −3.57 | −3.44 | −3.35 | −3.26 |
| 4 | 500 | −4.67 | −4.38 | −4.13 | −3.95 | −3.81 | −3.71 | −3.61 |
| 5 | 500 | −4.99 | −4.67 | −4.40 | −4.25 | −4.14 | −4.04 | −3.94 |
| | | | | *Case 2* | | | | |
| 1 | 500 | −3.96 | −3.64 | −3.37 | −3.20 | −3.07 | −2.96 | −2.86 |
| 2 | 500 | −4.31 | −4.02 | −3.77 | −3.58 | −3.45 | −3.35 | −3.26 |
| 3 | 500 | −4.73 | −4.37 | −4.11 | −3.96 | −3.83 | −3.73 | −3.65 |
| 4 | 500 | −5.07 | −4.71 | −4.45 | −4.29 | −4.16 | −4.05 | −3.96 |
| 5 | 500 | −5.28 | −4.98 | −4.71 | −4.56 | −4.43 | −4.33 | −4.24 |
| | | | | *Case 3* | | | | |
| 1 | 500 | −3.98 | −3.68 | −3.42 | — | −3.13 | — | — |
| 2 | 500 | −4.36 | −4.07 | −3.80 | −3.65 | −3.52 | −3.42 | −3.33 |
| 3 | 500 | −4.65 | −4.39 | −4.16 | −3.98 | −3.84 | −3.74 | −3.66 |
| 4 | 500 | −5.04 | −4.77 | −4.49 | −4.32 | −4.20 | −4.08 | −4.00 |
| 5 | 500 | −5.36 | −5.02 | −4.74 | −4.58 | −4.46 | −4.36 | −4.28 |

The probability shown at the head of the column is the area in the left-hand tail.

*Source:* P. C. B. Phillips and S. Ouliaris, "Asymptotic Properties of Residual Based Tests for Cointegration," *Econometrica* 58 (1990), p. 190. Also Wayne A. Fuller, *Introduction to Statistical Time Series*, Wiley, New York, 1976, p. 373.

# 18 APPENDIX F

Please find the bitmap version of the model for the HES on the CD provided.

CD/HES/HES bitmap - SD model

# 19 APPENDIX G

Please find the bitmap version of the model for the Public sector on the CD provided.

CD/HES/Pub bitmap - SD model

# 20 APPENDIX H

Please find the bitmap version of the model for the Private sector on the CD provided.

CD/HES/Priv bitmap - SD model

# 19 APPENDIX I: SENSITVITY ANALYSIS - DELPHI STUDY

A sensitivity analysis is conducted of the Delphi responses obtained from the survey conducted in the research project. This analysis is done in order to determine if there is any reason for concern that there could exist some level of sub-aggregation within the individual group members of the three sectors surveyed (HES, Public Sector and Private Sector). If such a sub aggregation should exist, it could affect the reliability of the responses.

Sensitivity analysis of the responses is conducted by analysing responses aggregated in groups from the three sectors surveyed. The main purpose of doing this is to investigate if group aggregations do exist and if so to which extend. It must however also be kept in mind that dividing the already relatively small sample into the three sector groupings leave us with very small samples (5 responses for the three sectors – although 1 from the HES dropped out in the last round).

A simple analysis is done: The means and medians of the different groups are compared to investigate the possibility of a sub-aggregation within the groups members of the three sectors surveyed. If a significant difference in the mean or median is found the Standard deviation is investigated – if the sub-groups also have a high standard deviation, it can be concluded that there exists an overall low level of consensus. However if the overall level of consensus is low, but a high level of consensus is achieved in the sub-groups, it could indicate a sub-aggregation for that response – potentially skewing the results.

## 19.1 The Higher Education Sector: Delphi sensitivity analysis

In order to save space in the box plots as well as in the tables, the questions in the survey is reference to the question number. The following table serves as a reference for the coding of the issue categories.

**Table 19-1: Numbering of survey questions**

| Issue Category |
|---|
| **Q1. Lack of funding for R&D in the HES** |
| **Q2. Lack of multidisciplinary research projects** |
| **Q3. Poor linkages pose a threat to future capacity and the relevance of R&D performed in the system** |
| **Q4. Inability to retain and rejuvenate human resource stock in the system** |
| **Q5. The deterioration of quality of human resources working in R&D in the sector** |
| **Q6. Inadequate funding of equipment** |
| **Q7. The lack of female and black researchers for R&D to reach representative work force** |
| **Q8. Difficulty of successful R&D policy alignment with national priorities** |
| **Q9. Weak IP protection policies in HES** |

The following box plot is a visual representation of the responses received from respondents from all three sectors.

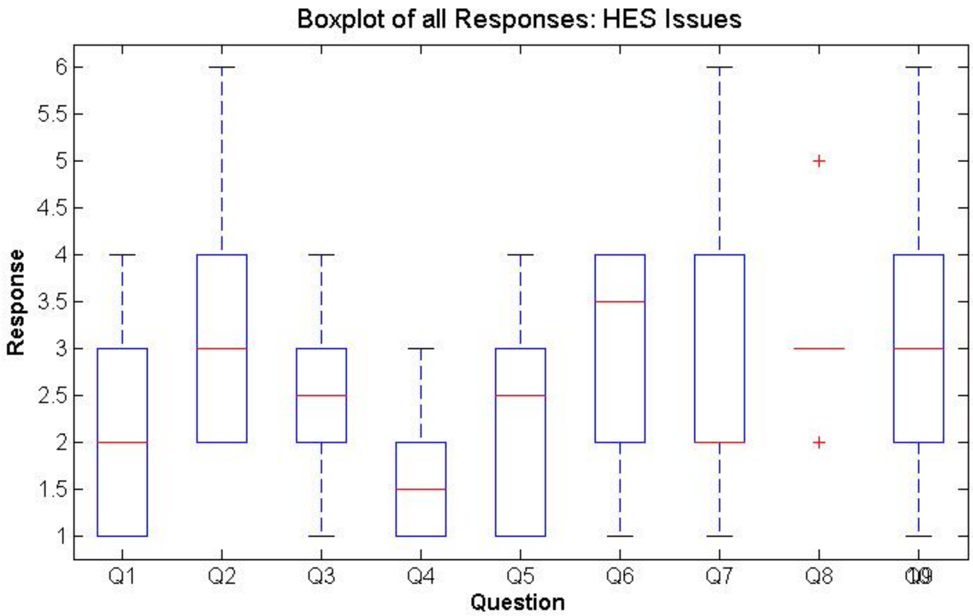


**Figure 19-1: Box plot of Responses from all respondents: Issues in the HES**

The following tables summarise the analysis done on the set of responses from all respondents.

**Table 19-2: Summary of responses from all respondents: Issues in HES**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2.29 | 3.29 | 2.43 | 1.64 | 2.43 | 3.14 | 2.71 | 3.29 | 3.36 |
| **Median** | 2.00 | 3.00 | 2.50 | 1.50 | 2.50 | 3.50 | 2.00 | 3.00 | 3.00 |
| **St. Dev** | 1.14 | 1.59 | 0.85 | 0.74 | 1.16 | 1.03 | 1.54 | 0.99 | 1.39 |
| **Upper Quartile** | 4.00 | 6.00 | 4.00 | 3.00 | 4.00 | 4.00 | 6.00 | 5.00 | 6.00 |
| **Lower Quartile** | 1.25 | 2.00 | 2.00 | 1.00 | 1.25 | 2.25 | 2.00 | 3.00 | 2.25 |
| **Maximum** | 4 | 6 | 4 | 3 | 4 | 4 | 6 | 5 | 6 |
| **Minimum** | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |

**Table 19-3: Summary of responses from HES respondents: Issues in HES**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 1.3 | 3.8 | 2.8 | 1.5 | 1.8 | 2.3 | 3.0 | 3.3 | 4.3 |
| **Median** | 1.0 | 3.0 | 2.5 | 1.5 | 1.5 | 2.5 | 3.5 | 3.0 | 4.5 |
| **St. Dev** | 0.5 | 1.5 | 1.0 | 0.6 | 1.0 | 1.0 | 1.4 | 1.3 | 1.0 |
| **Upper Quartile** | 2.0 | 6.0 | 4.0 | 2.0 | 3.0 | 3.0 | 4.0 | 5.0 | 5.0 |
| **Lower Quartile** | 1.0 | 3.0 | 2.0 | 1.0 | 1.0 | 1.8 | 2.5 | 2.8 | 3.8 |
| **Maximum** | 2.0 | 6.0 | 4.0 | 2.0 | 3.0 | 3.0 | 4.0 | 5.0 | 5.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1.0 | 3.0 | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 3.0 |

**Table 19-4: Summary of responses from Public Sector respondents: Issues in HES**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 3 | 4 | 3 | 2 | 3 | 3 | 2 | 4 | 3 |
| **Median** | 2 | 4 | 3 | 2 | 3 | 4 | 2 | 3 | 3 |
| **St. Dev** | 1.00 | 1.71 | 0.50 | 0.58 | 0.82 | 0.96 | 0.00 | 1.00 | 0.58 |
| **Upper Quartile** | 4 | 6 | 3 | 2 | 4 | 4 | 2 | 5 | 3 |
| **Lower Quartile** | 2 | 2.75 | 2.75 | 1 | 2.75 | 2.75 | 2 | 3 | 2 |
| **Maximum** | 4 | 6 | 3 | 2 | 4 | 4 | 2 | 5 | 3 |
| **Minimum** | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 2 |

**Table 19-5: Summary of responses from Public Sector respondents: Issues in HES**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2.8 | 2.7 | 2.0 | 1.8 | 2.5 | 3.7 | 3.0 | 3.2 | 3.3 |
| **Median** | 3.0 | 2.0 | 2.0 | 1.5 | 2.5 | 4.0 | 2.5 | 3.0 | 3.5 |
| **St. Dev** | 1.2 | 1.6 | 0.9 | 1.0 | 1.4 | 0.8 | 2.1 | 1.0 | 1.8 |
| **Upper Quartile** | 4.0 | 6.0 | 3.0 | 3.0 | 4.0 | 4.0 | 6.0 | 5.0 | 6.0 |
| **Lower Quartile** | 2.3 | 2.0 | 1.3 | 1.0 | 1.3 | 4.0 | 1.3 | 3.0 | 2.3 |
| **Maximum** | 4 | 6 | 3 | 3 | 4 | 4 | 6 | 5 | 6 |
| **Minimum** | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 |

The following table summarises a comparison of means between the three sectors surveyed. The mean is rounded as to give a better sense which main category each group opinion fall into.

**Table 19-6: Comparison of means (HES issues)**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 3 |
| **HES** | 1 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 4 |
| **PUB** | 3 | 4 | 3 | 2 | 3 | 3 | 2 | 4 | 3 |
| **Private** | 3 | 3 | 2 | 2 | 3 | 4 | 3 | 3 | 3 |

The following figure is a graphical representation of the data in the table:

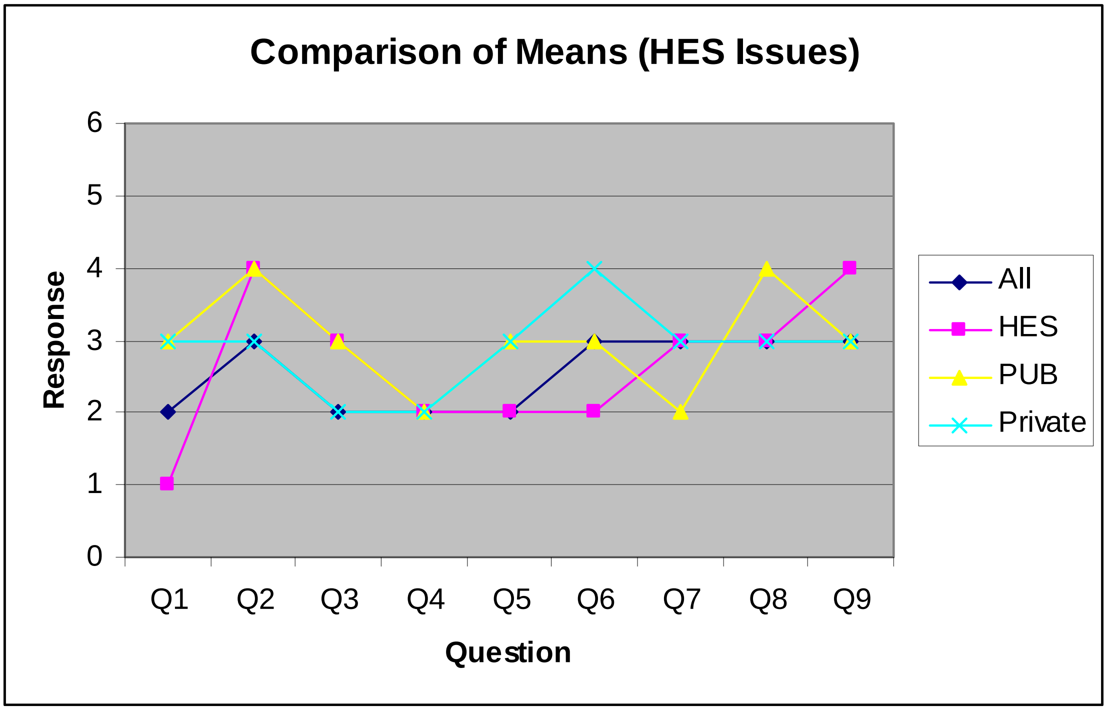


**Figure 19-2: Graphical representation of the Comparison of Means (HES Issues)**

The following table summarises the comparison of medians between the three sectors surveyed.

**Table 19-7: Comparison of Medians (HES Issues)**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Median** | 2 | 3 | 2 | 2 | 3 | 4 | 2 | 3 | 3 |
| **HES** | 1 | 3 | 3 | 2 | 2 | 3 | 4 | 3. | 5 |
| **PUB** | 2 | 4 | 3 | 2 | 3 | 4 | 2 | 3 | 3 |
| **Private** | 3 | 3 | 2 | 2 | 3 | 4 | 3 | 3 | 3 |

The following figure is a graphical representation of the data in the table:

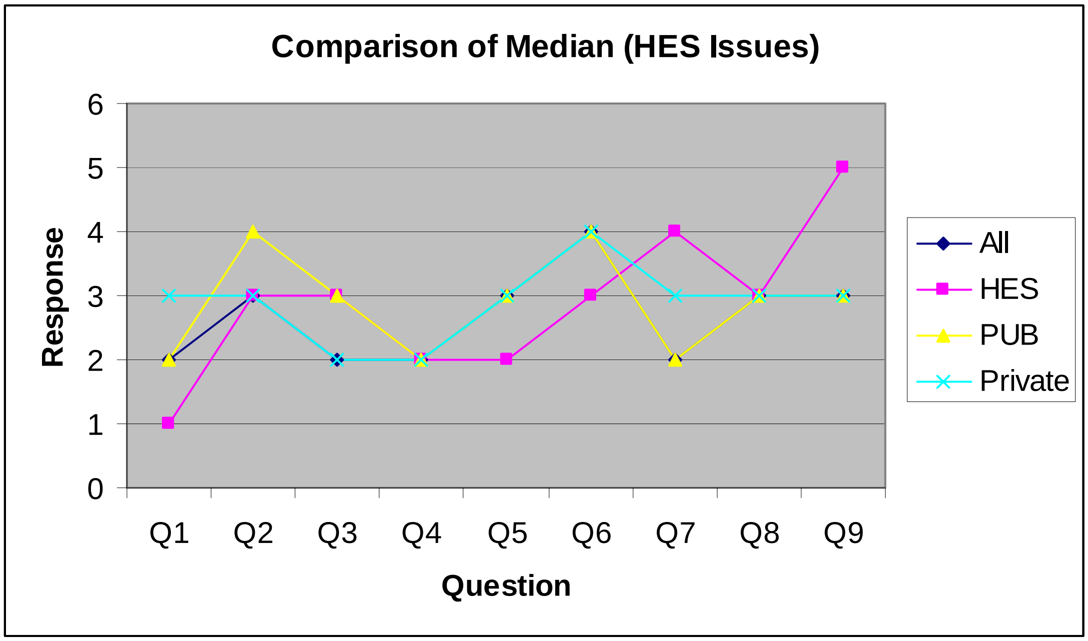


**Figure 19-3: Graphical representation of the Comparison of Medians (HES Issues)**

No consistent trend or major differences can be seen from the mean and the median of the three groups. It can therefore be concluded that no obvious sub-aggregation that could skew the overall result exist in the groups surveyed.

Although not explicitly included in the analysis, the box plots for each one of the sub aggregations are also provided.

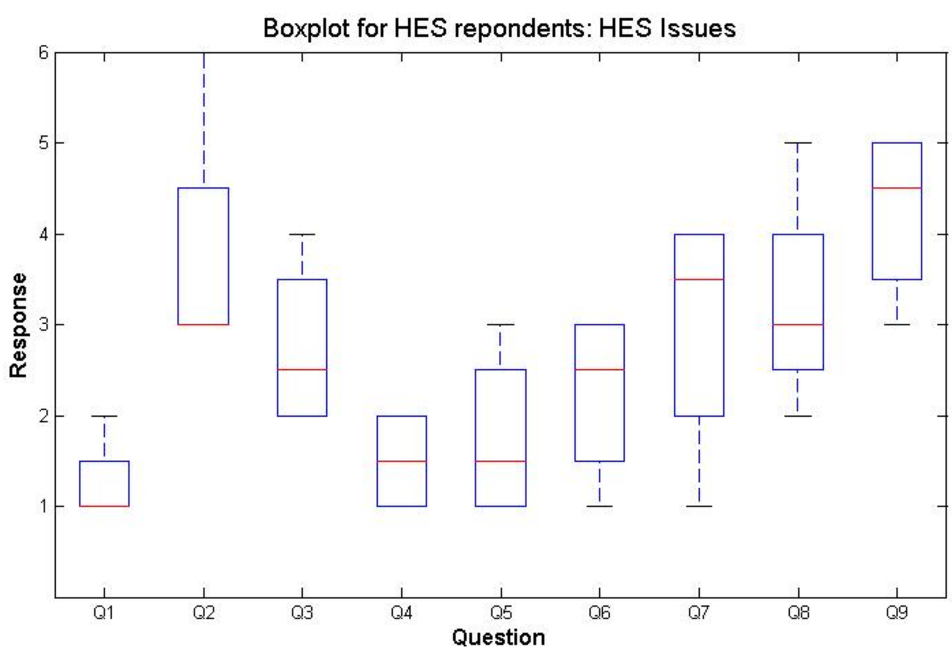


**Figure 19-4: Box plot for HES respondents: HES issues**

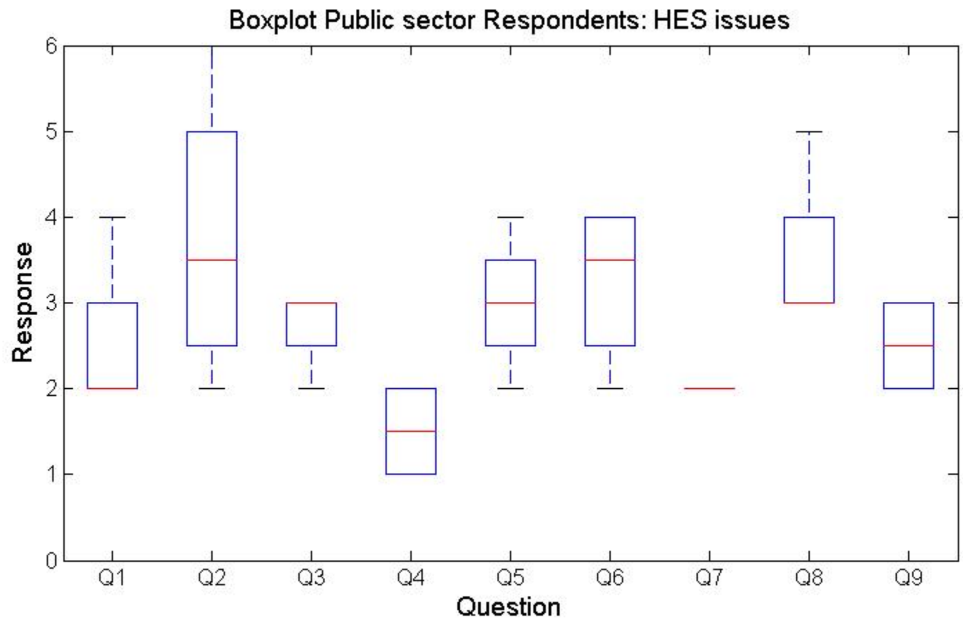


**Figure 19-5: Box plot for Public sector respondents: HES issues**

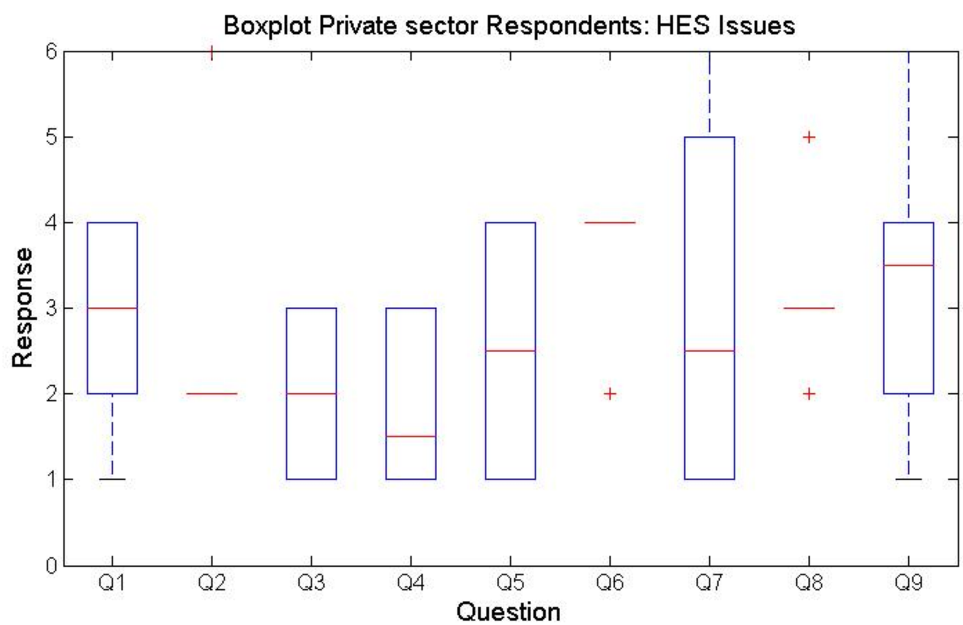


**Figure 19-6: Box plot for Private sector respondents: HES issues**

## 19.2 The Public Sector: Delphi sensitivity analysis

In order to save space in the box plots as well as in the tables, the questions in the survey is reference to the question number. The following table serves as a reference for the coding of the issue categories.

**Table 19-8: Numbering of survey questions for Public sector**

| Issue Category |
|---|
| Q1. Inability to retain and rejuvenate the researchers stock in the system |
| Q2. Lack of government funding to the public sector to develop R&D and technology platforms |
| Q3. Deterioration of quality of human resources working in R&D |
| Q4. Current BEE policies having a negative effect on quality and R&D capacity |
| Q5. A lack of direction and leadership in science policy |

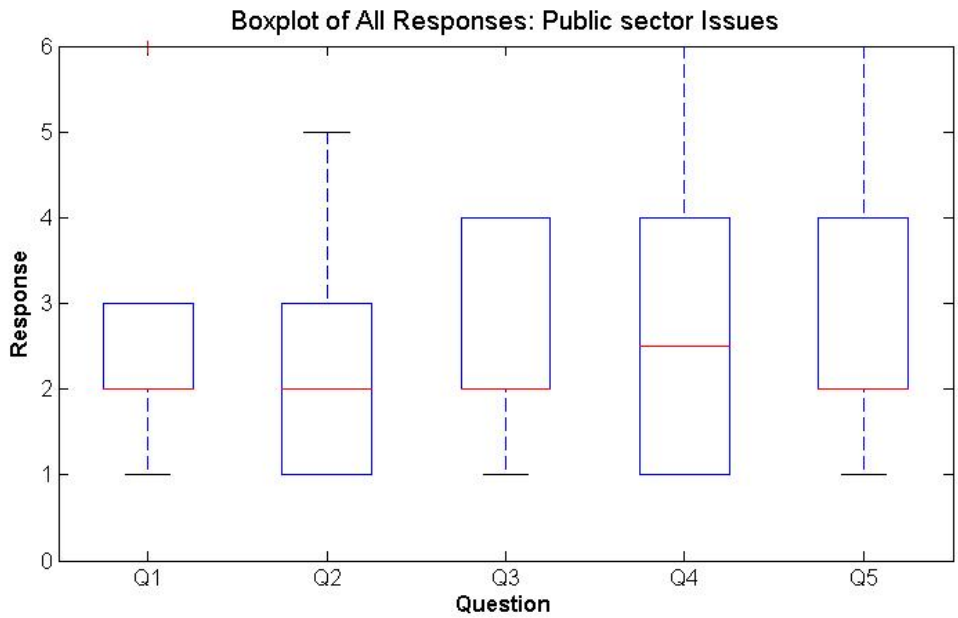


**Figure 19-7: Box plot of Responses from all respondents: Issues in the Public sector**

The following table summarises the analysis done on the set of responses from all respondents:

**Table 19-9: Summary of responses from All respondents: Issues in Public Sector**

| | Q1 | Q2 | Q3 | Q4 | Q5 |
|---|---|---|---|---|---|
| **Mean** | 2.43 | 2.21 | 2.43 | 2.86 | 2.79 |
| **Median** | 2.00 | 2.00 | 2.00 | 2.50 | 2.00 |
| **St. Dev** | 1.16 | 1.31 | 1.16 | 1.70 | 1.48 |
| **Upper Quartile** | 6 | 5 | 4 | 6 | 6 |
| **Lower Quartile** | 2 | 1 | 2 | 1.25 | 2 |
| **Maximum** | 6 | 5 | 4 | 6 | 6 |
| **Minimum** | 1 | 1 | 1 | 1 | 1 |

**Table 19-10: Summary of responses from HES respondents: Issues in Public Sector**

| | Q1 | Q2 | Q3 | Q4 | Q5 |
|---|---|---|---|---|---|
| **Mean** | 3.25 | 2.25 | 2 | 1.75 | 2 |
| **Median** | 2.5 | 2.5 | 2 | 1.5 | 2 |
| **St. Dev** | 1.89 | 0.96 | 0.82 | 0.96 | 0.82 |

| | | | | | |
|---|---|---|---|---|---|
| **Upper Quartile** | 6 | 3 | 3 | 3 | 3 |
| **Lower Quartile** | 2 | 1.75 | 1.75 | 1 | 1.75 |
| **Maximum** | 6 | 3 | 3 | 3 | 3 |
| **Minimum** | 2 | 1 | 1 | 1 | 1 |

**Table 19-11: Summary of responses from Public Sector respondents: Issues in Public Sector**

| | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
|---|---|---|---|---|---|
| **Mean** | 1.75 | 1.50 | 3.00 | 3.50 | 4.25 |
| **Median** | 2.00 | 1.00 | 3.00 | 3.50 | 4.50 |
| **St. Dev** | 0.50 | 1.00 | 1.15 | 1.29 | 1.71 |
| **Upper Quartile** | 2 | 3 | 4 | 5 | 6 |
| **Lower Quartile** | 1.75 | 1 | 2 | 2.75 | 3.5 |
| **Maximum** | 2 | 3 | 4 | 5 | 6 |
| **Minimum** | 1 | 1 | 2 | 2 | 2 |

**Table 19-12: Summary of responses from Private Sector respondents: Issues in Public Sector**

| | Q1 | Q2 | Q3 | Q4 | Q5 |
|---|---|---|---|---|---|
| Mean | 2.43 | 2.21 | 2.43 | 2.86 | 2.79 |
| Median | 2.00 | 2.00 | 2.00 | 2.50 | 2.00 |
| Stdev | 1.16 | 1.31 | 1.16 | 1.70 | 1.48 |
| Upper Quartile | 6 | 5 | 4 | 6 | 6 |
| Lower Quartile | 2 | 1 | 2 | 1.25 | 2 |
| Maximum | 6 | 5 | 4 | 6 | 6 |
| Minimum | 1 | 1 | 1 | 1 | 1 |

The following table summarises a comparison of means between the three sectors surveyed. The mean is rounded as to give a better sense which main category each group opinion fall into.

**Table 19-13: Comparison of means (Public Sector issues)**

| | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
|---|---|---|---|---|---|
| **Mean** | 2 | 2 | 2 | 3 | 3 |
| **HES** | 3 | 2 | 2 | 2 | 2 |
| **PUB** | 2 | 2 | 3 | 4 | 4 |
| **Private** | 2 | 2 | 2 | 3 | 3 |

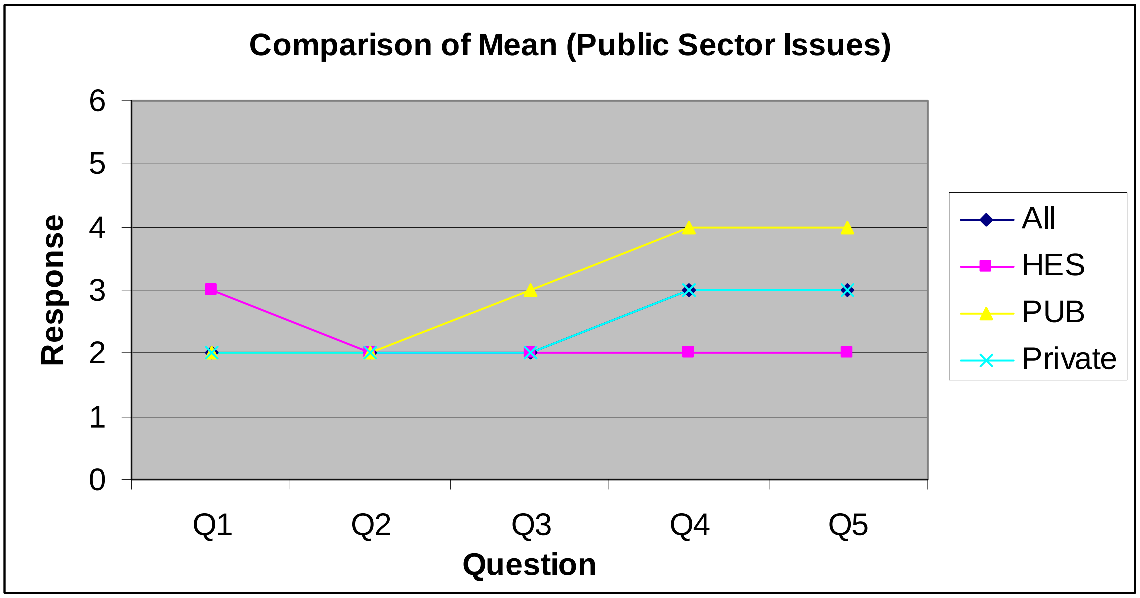


**Figure 19-8: Graphical representation of the Comparison of Means (Pub. Sector Issues)**

The following table summarises the comparison of medians between the three sectors surveyed.

**Table 19-14: Comparison of Medians (HES Issues)**

| | Q1 | Q2 | Q3 | Q4 | Q5 |
|---|---|---|---|---|---|
| **Mean** | 2 | 2 | 2 | 2.5 | 2 |
| **HES** | 2.5 | 2.5 | 2 | 1.5 | 2 |
| **PUB** | 2 | 1 | 3 | 3.5 | 4.5 |
| **Private** | 2 | 2 | 2 | 2.5 | 2 |

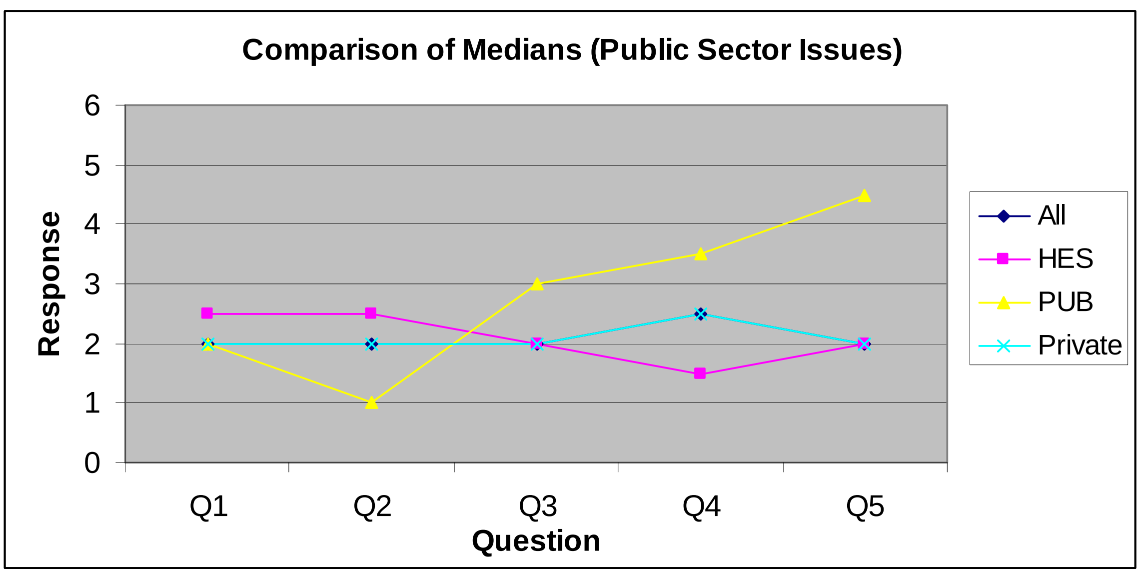


**Figure 19-9: Graphical representation of the Comparison of Medians (Pub. Sector Issues)**

Q4 and Q5 show larger differences between the three sectors in terms of the Median value. From this we have to investigate the possibility that homogeneity in the responses from the three sectors could be skewing the results.

**Table 19-15: Summary of St.DEv (Private sector issues)**

| | Q1 | Q2 | Q3 | Q4 | Q5 |
|---|---|---|---|---|---|
| **Overall** | 1.16 | 1.31 | 1.16 | 1.70 | 1.48 |
| **HES** | 1.89 | 0.96 | 0.82 | 0.96 | 0.82 |
| **PUB** | 0.50 | 1.00 | 1.15 | 1.29 | 1.71 |
| **Private** | 1.16 | 1.31 | 1.16 | 1.70 | 1.48 |

We however find that the resulting high standard deviation for the whole response set is also present within the response sets from the three sectors for these three questions. The high Standard Deviation for Q4, Q5 indicates a low overall level of consensus within the groups. We can therefore conclude that the high overall standard deviation is not a low level of consensus due to homogeneity on responses from the three sectors. We can therefore conclude that for the purpose of this study we can be satisfied that the responses are heterogeneous for this sector.

Although not explicitly included in the analysis, the box plots for each one of the sub aggregations are also provided.

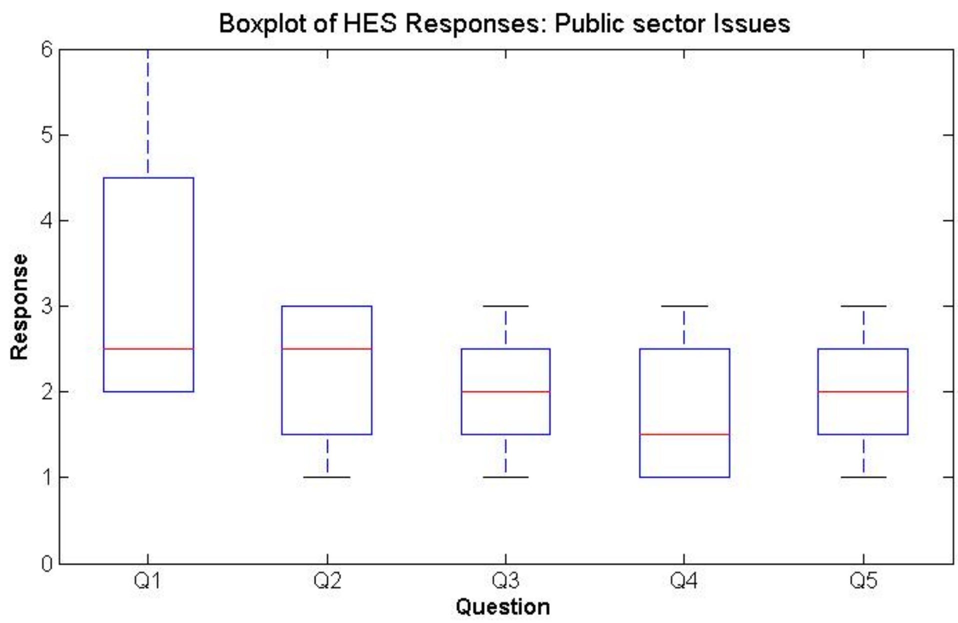


**Figure 19-10: Box plot of Responses from HES respondents: Issues in the Public sector**

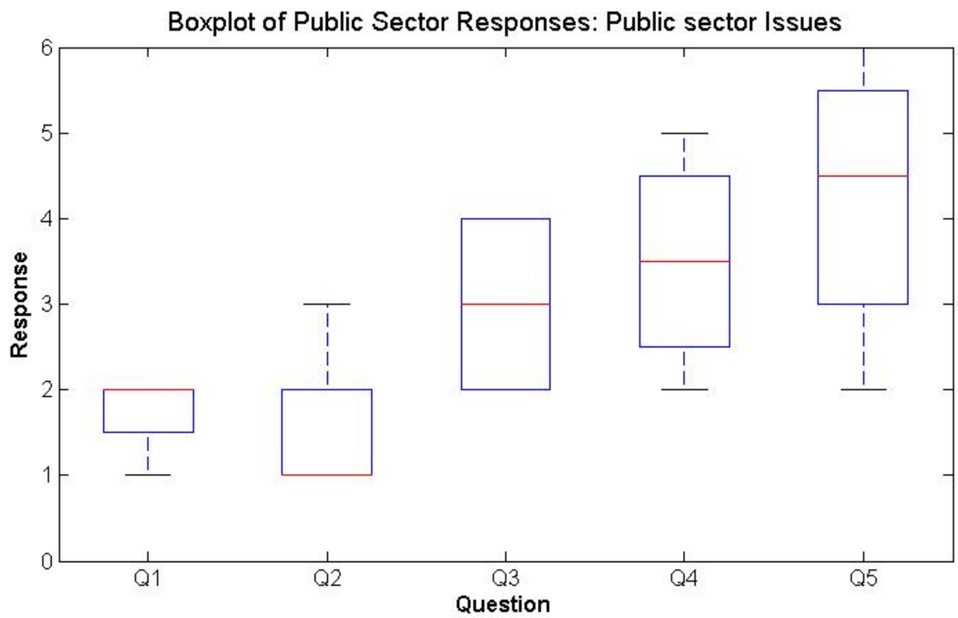


**Figure 19-11: Box plot of Responses from Public sector respondents: Issues in the Public sector**

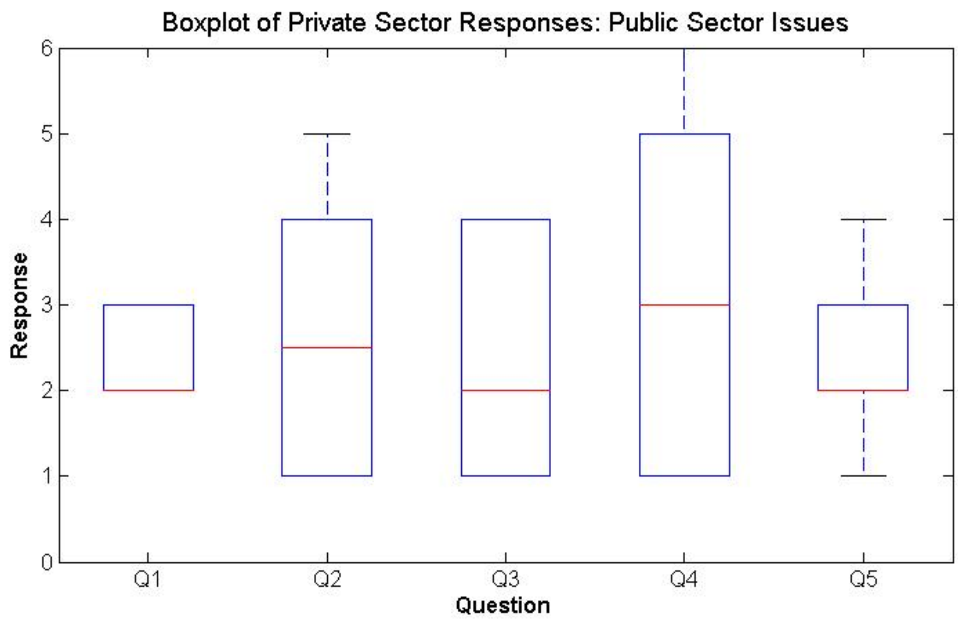


**Figure 19-12: Box plot of Responses from Private sector respondents: Issues in the Public sector**

## 19.3 The Private Sector: Delphi sensitivity analysis

In order to save space in the box plots as well as in the tables, the questions in the survey is reference to the question number. The following table serves as a reference for the coding of the issue categories.

**Table 19-16: Numbering of survey questions for Public sector**

| Issue Category |
|---|
| Q1. Lack of research culture in South Africa |
| Q2. Lack of fiscal incentives from government to foster R&D culture in companies |
| Q3. Lack of funding of R&D |
| Q4. Inability to retain and rejuvenate the researchers stock in the system |
| Q5. Deterioration of quality (skill level) of human resources working in R&D |
| Q6. Current BEE policies will have a negative effect on South Africa's future R&D capacity |
| Q7. Poor linkages |
| Q8. Lack of direction and leadership in science policy |
| Q9. Restrictive communication infrastructure |

The following box plot is a visual representation of the responses received from respondents from all three sectors.

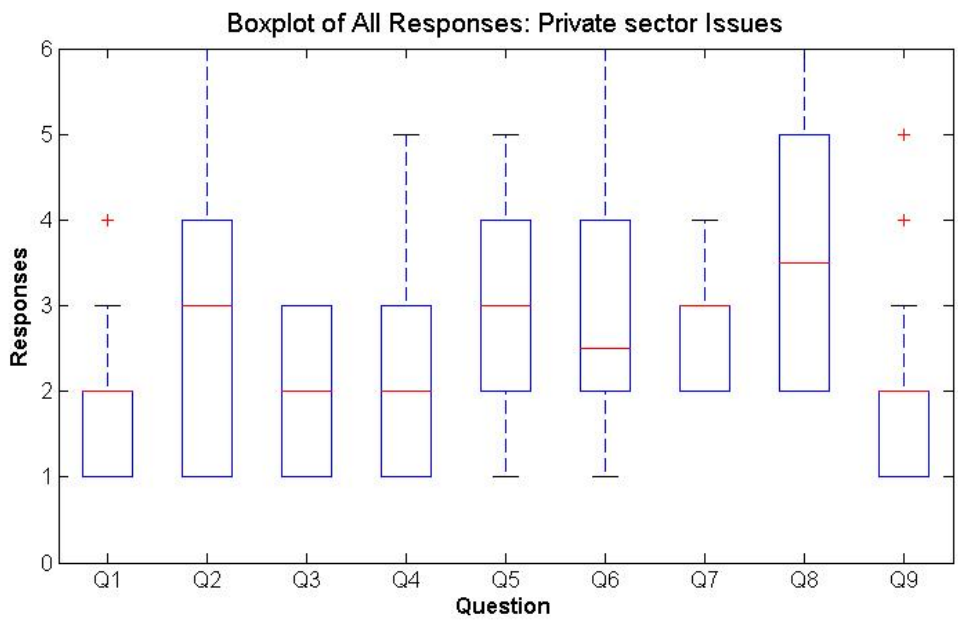


**Figure 19-13: Box plot of Responses from all respondents: Issues in the Private sector**

The following tables summarise the analysis done on the set of responses from all respondents.

**Table 19-17: Summary of responses from all respondents: Issues in Private Sector**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 4 | 2 |
| **Median** | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 4 | 2 |
| **St. Dev** | 0.86 | 1.64 | 0.83 | 1.20 | 1.30 | 1.59 | 0.63 | 1.49 | 1.21 |
| **Upper Quartile** | 4 | 6 | 3 | 5 | 5 | 6 | 4 | 6 | 5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Lower Quartile** | 1 | 1 | 1.25 | 1.25 | 2 | 2 | 2 | 2.25 | 1 |
| **Maximum** | 4 | 6 | 3 | 5 | 5 | 6 | 4 | 6 | 5 |
| **Minimum** | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |

**Table 19-18: Summary of responses from HES respondents: Issues in Private Sector**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 2 |
| **Median** | 2 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 2 |
| **St. Dev** | 0.58 | 0.50 | 0.96 | 0.50 | 0.82 | 0.58 | 0.82 | 0.58 | 1.41 |
| **Upper Quartile** | 2 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 4 |
| **Lower Quartile** | 1 | 1 | 1 | 1.75 | 1.75 | 1 | 2.75 | 2 | 1 |
| **Maximum** | 2 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 4 |
| **Minimum** | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |

**Table 19-19: Summary of responses from Public sector respondents: Issues in Private Sector**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2 | 5 | 3 | 2 | 4 | 4 | 2 | 5 | 2 |
| **Median** | 2 | 5 | 3 | 2 | 4 | 4 | 2 | 5 | 2 |
| **St. Dev** | 0 | 1.3 | 0.6 | 1 | 0.6 | 1.3 | 0.5 | 1.3 | 0 |
| **Upper Quartile** | 2 | 6 | 3 | 3 | 4 | 5 | 3 | 6 | 2 |
| **Lower Quartile** | 2 | 3.75 | 2 | 1 | 3 | 2.75 | 2 | 3.75 | 2 |
| **Maximum** | 2 | 6 | 3 | 3 | 4 | 5 | 3 | 6 | 2 |
| **Minimum** | 2 | 3 | 2 | 1 | 3 | 2 | 2 | 3 | 2 |

**Table 19-20: Summary of responses from Private sector respondents: Issues in Private Sector**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2.0 | 2.5 | 2.0 | 3.0 | 3.3 | 3.5 | 2.7 | 4.0 | 2.2 |
| **Median** | 1.5 | 3.0 | 2.0 | 3.0 | 3.5 | 4.0 | 3.0 | 4.5 | 1.5 |
| **St. Dev** | 1.3 | 1.2 | 0.9 | 1.4 | 1.6 | 1.8 | 0.5 | 1.7 | 1.6 |
| **Upper Quartile** | 4.0 | 4.0 | 3.0 | 5.0 | 5.0 | 6.0 | 3.0 | 6.0 | 5.0 |
| **Lower Quartile** | 1.0 | 1.5 | 1.3 | 2.3 | 2.3 | 2.5 | 2.3 | 2.5 | 1.0 |
| **Maximum** | 4 | 4 | 3 | 5 | 5 | 6 | 3 | 6 | 5 |
| **Minimum** | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |

The following table summarises a comparison of means between the three sectors surveyed. The mean is rounded as to give a better sense which main category each group opinion fall into.

**Table 19-21: Comparison of means (Private sector issues)**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 4 | 2 |
| **HES** | 2 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 2 |
| **PUB** | 2 | 5 | 3 | 2 | 4 | 4 | 2 | 5 | 2 |
| **Private** | 2 | 3 | 2 | 3 | 3 | 4 | 3 | 4 | 2 |

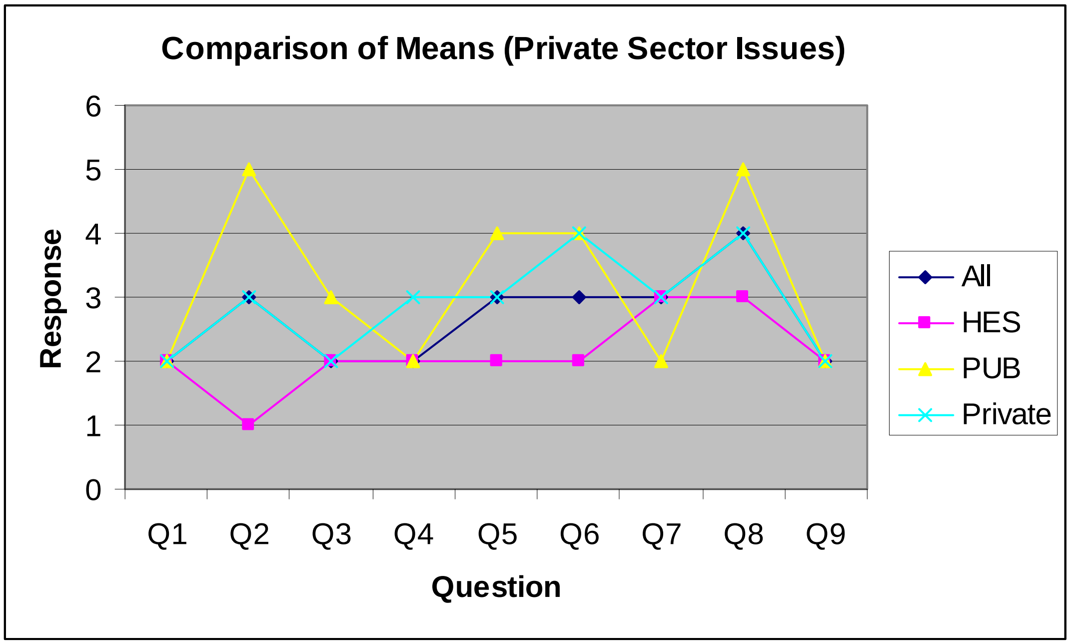


**Figure 19-14: Graphical representation of the Comparison of Means (Private Sector Issues)**

The following table summarises the comparison of medians between the three sectors surveyed.

**Table 19-22: Comparison of Medians (Private sector Issues)**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Median** | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 4 | 2 |
| **HES** | 2 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 2 |
| **PUB** | 2 | 5 | 3 | 2 | 4 | 4 | 2 | 5 | 2 |
| **Private** | 1.5 | 3.0 | 2.0 | 3.0 | 3.5 | 4.0 | 3.0 | 4.5 | 1.5 |

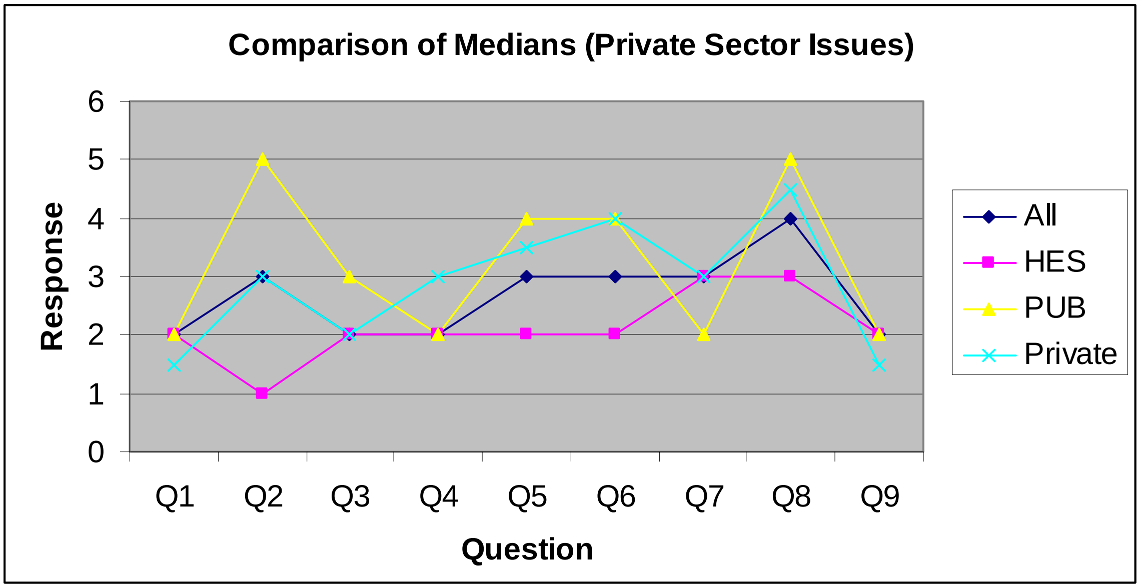


**Figure 19-15: Graphical representation of the Comparison of Medians (Private Sector Issues)**

For the Private sector analysis, the HES respondents in some cases seem to rank the issues as more serious than the other two groupings. However this trend was not evident in the analysis of the other two sectors.

Q2, Q5, and Q6 all show larger differences between the three sectors in terms of the Median value. From this we have to investigate the possibility that homogeneity in the responses from the three sectors could be skewing the results.

**Table 19-23: Summary of St.DEv (Private sector issues)**

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| **Overall** | 0.86 | 1.64 | 0.83 | 1.20 | 1.30 | 1.59 | 0.63 | 1.49 | 1.21 |
| **HES** | 0.58 | 0.50 | 0.96 | 0.50 | 0.82 | 0.58 | 0.82 | 0.58 | 1.41 |
| **PUB** | 0 | 1.3 | 0.6 | 1 | 0.6 | 1.3 | 0.5 | 1.3 | 0 |
| **Private** | 1.3 | 1.2 | 0.9 | 1.4 | 1.6 | 1.8 | 0.5 | 1.7 | 1.6 |

We however find that the resulting high standard deviation for the whole response set is also present within the response sets from the three sectors for these three questions. The high Standard Deviation for Q2, Q5 and Q6 indicates a low overall level of consensus within the groups. We can therefore conclude that the high overall standard deviation is not a low level of consensus due to homogeneity on responses from the three sectors. We can therefore conclude that for the purpose of this study we can be satisfied that the responses are heterogeneous for this sector.

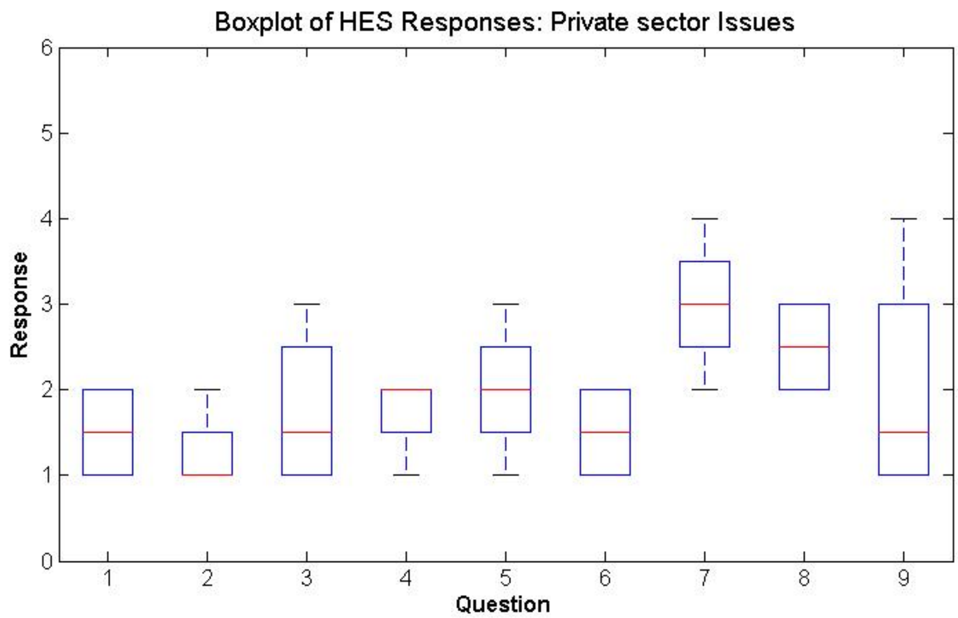


**Figure 19-16: Box plot of Responses from HES respondents: Issues in the Private sector**

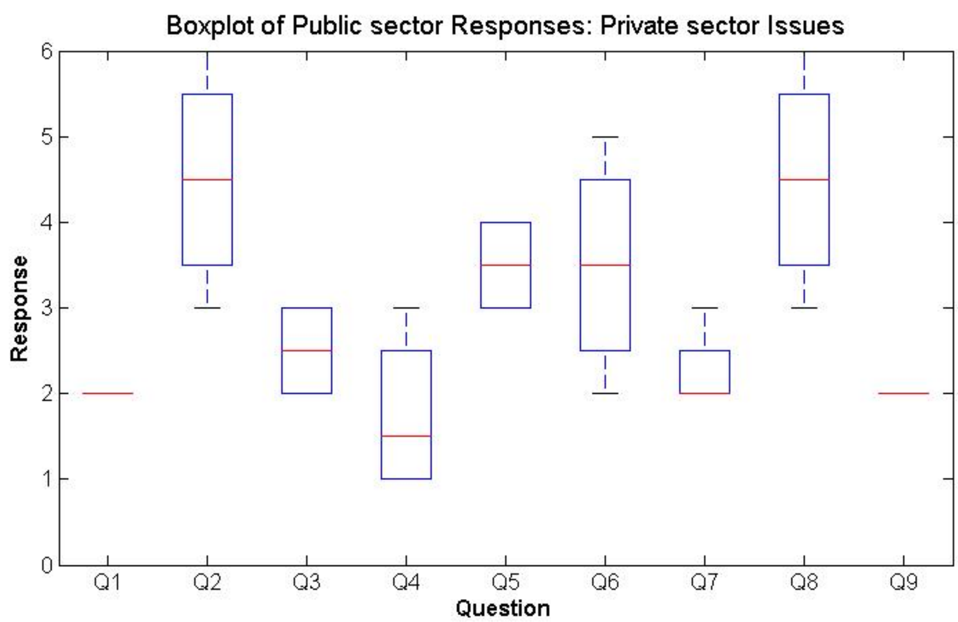


**Figure 19-17: Box plot of Responses from Public sector respondents: Issues in the Private sector**

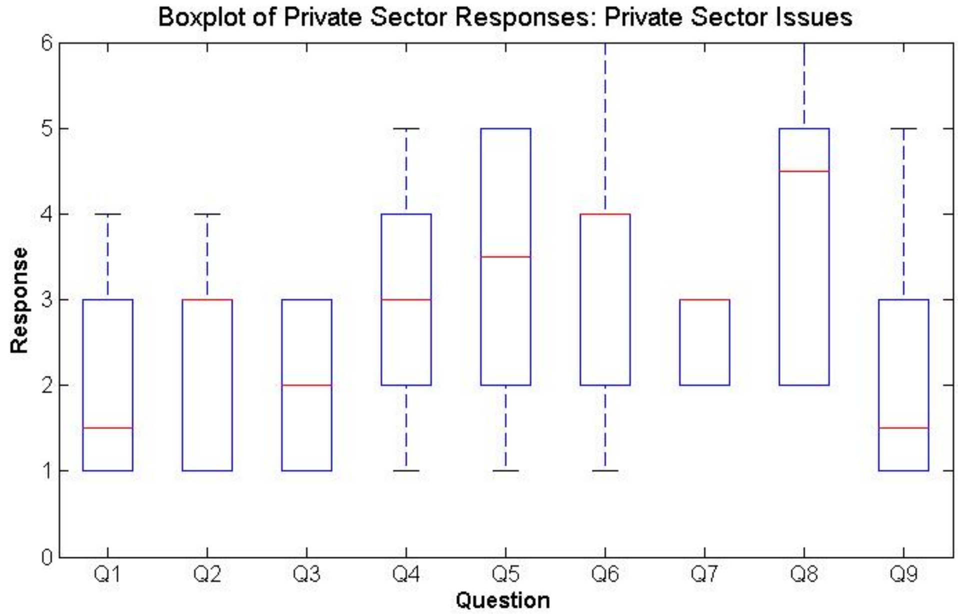


**Figure 19-18: Box plot of Responses from Private sector respondents: Issues in the Private sector**