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):

[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.

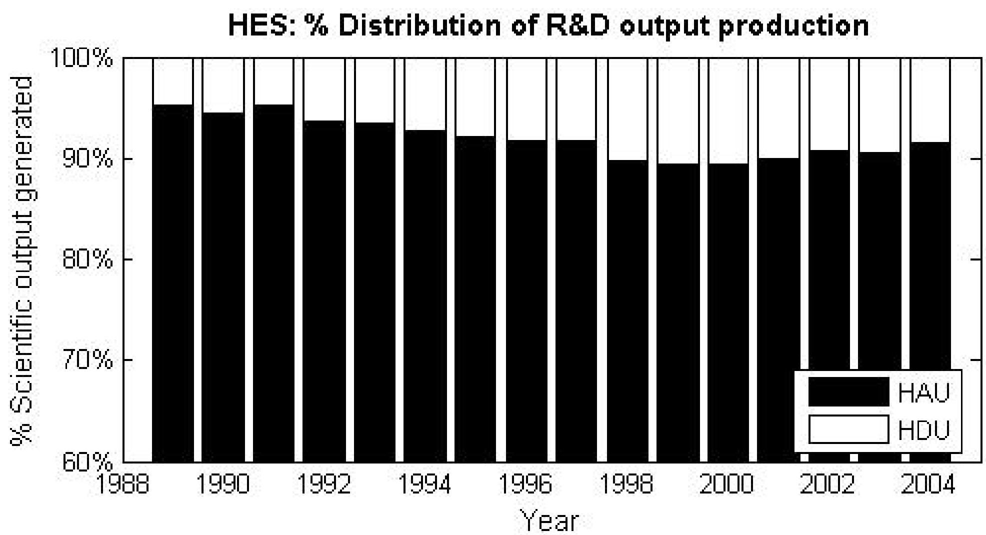


Figure 7-1 Distribution of R&D output generation in the HES

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 Expenditure on technicians 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%).

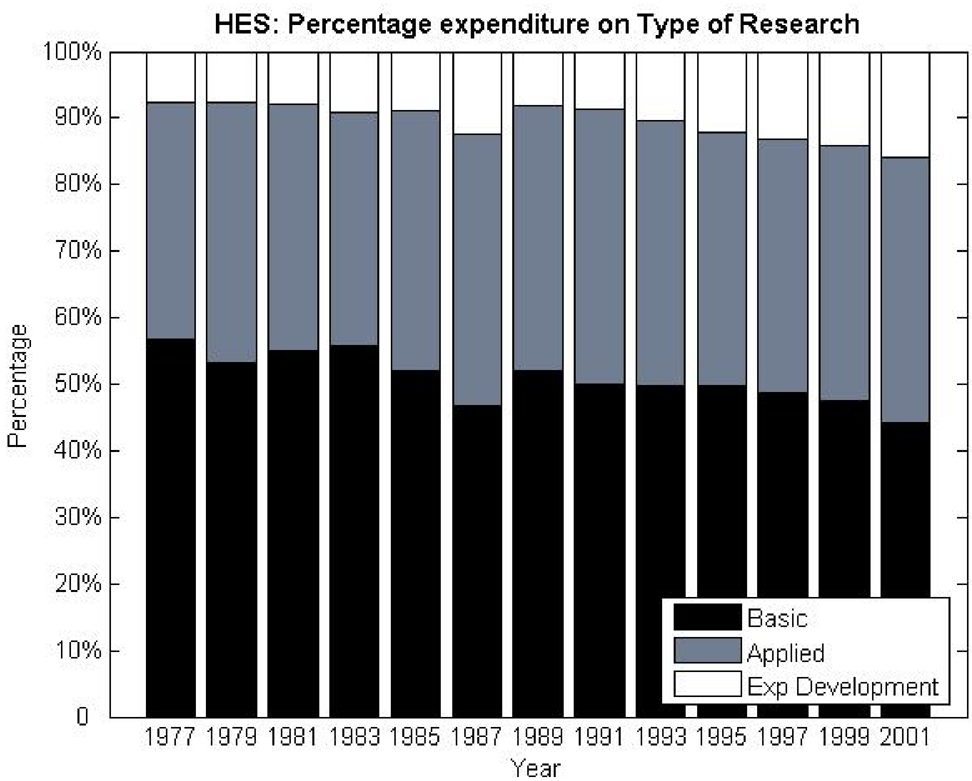


Figure 7-2: Distribution of Expenditure on R&D

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 Expenditure on technicians Expenditure on support staff	88.28% 8.00% 3.00%	6.52% 5.76% 1.04%
Percentage expenditure on basic research Percentage expenditure on applied research Percentage expenditure on experimental development	51.06% 38.45% 10.13%	4.27% 2.01% 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.**

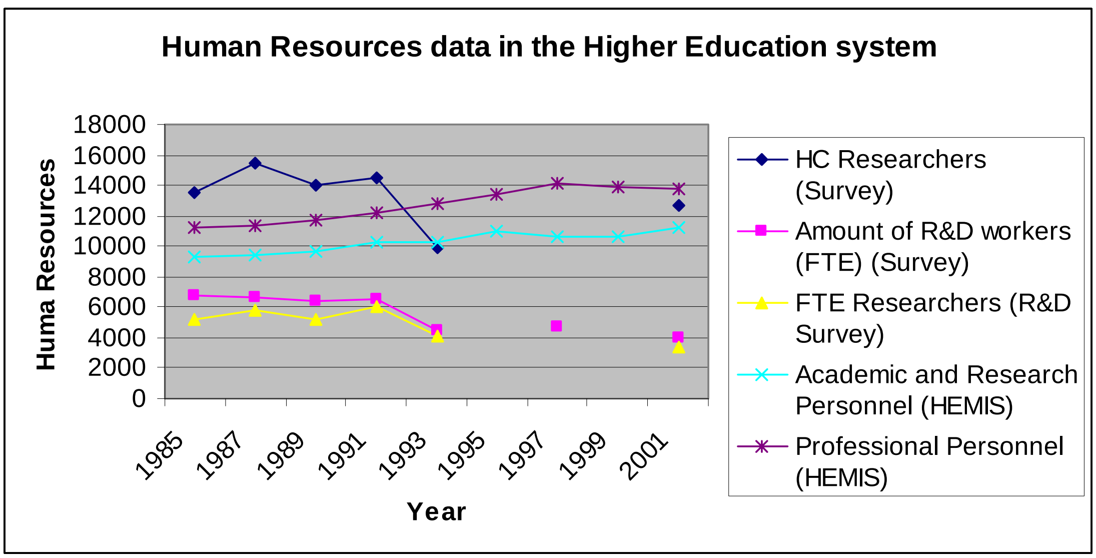


Figure 7-3 Data gathered for Human Resources in the HES

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.

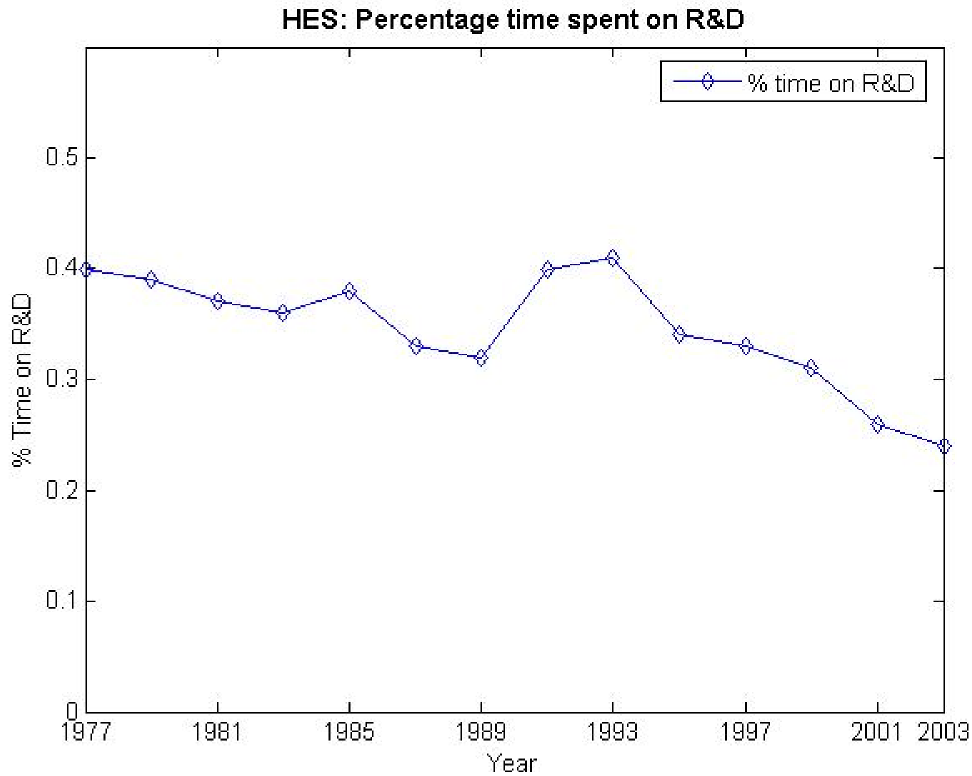


Figure 7-4 Trend line of Percentage Time spent by Researchers in the System

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.

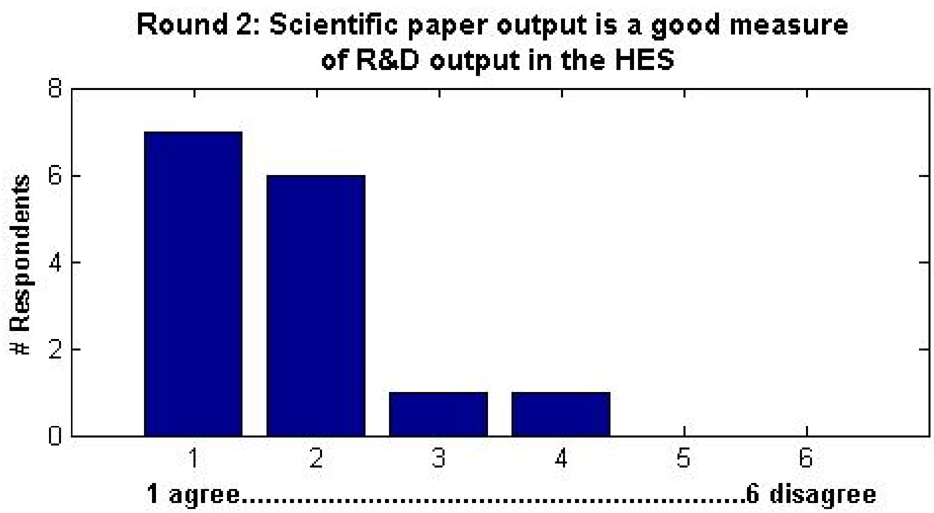


Figure 7-5: Scientific Output as a Measure of R&D Output in the HES

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

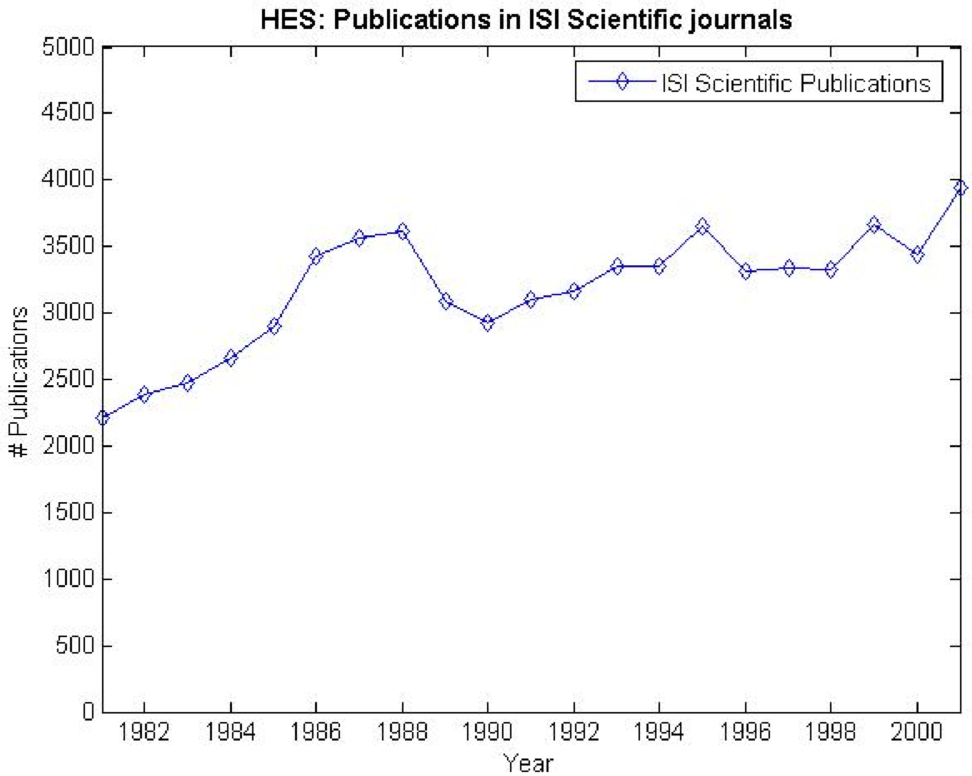


Figure 7-6 Scientific Papers generated in the South African HES

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.

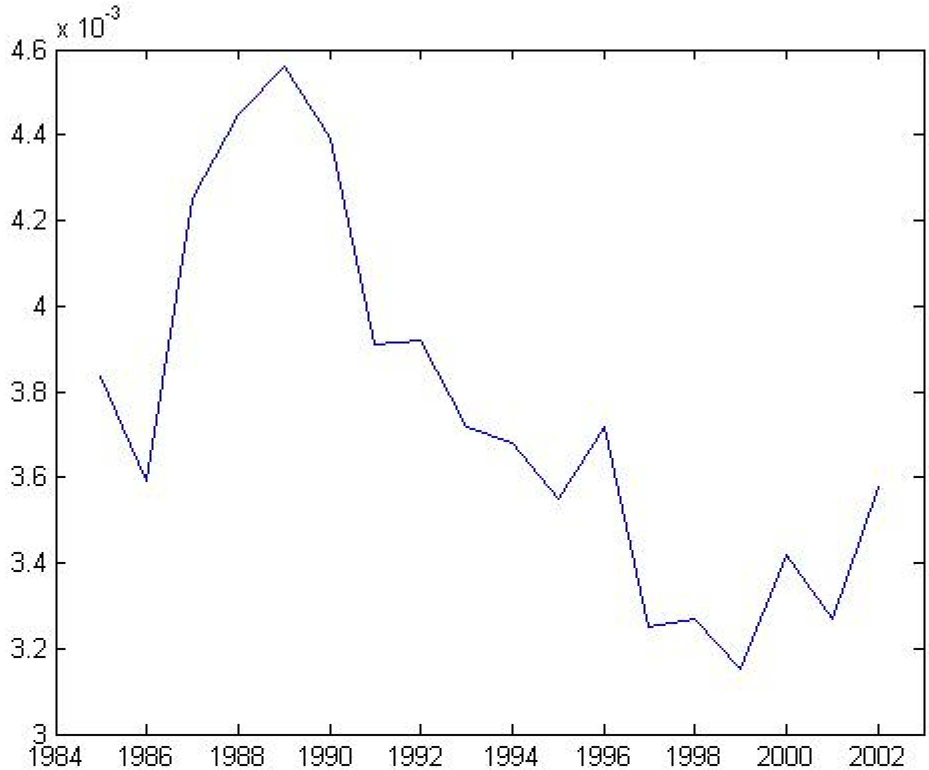


Figure 7-7: South Africa's share of world output in terms of ISI publications

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.

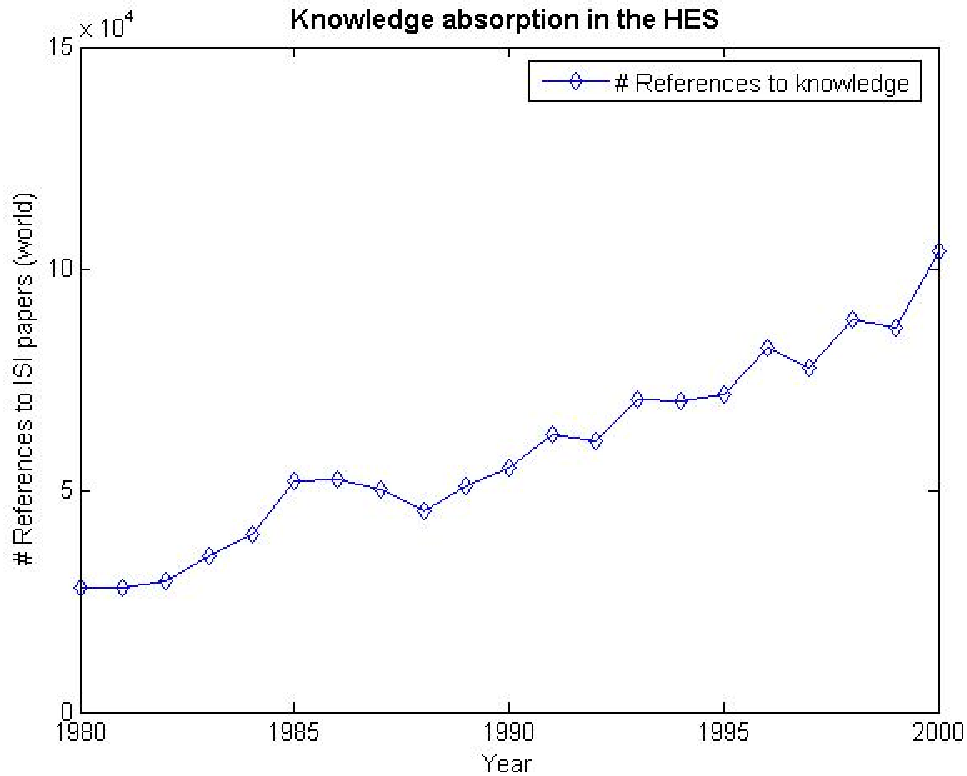


Figure 7-8.Number of references made to knowledge created in an external environment.

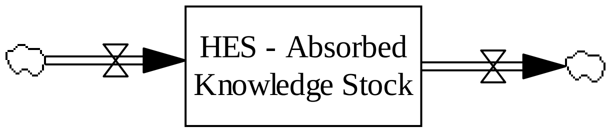
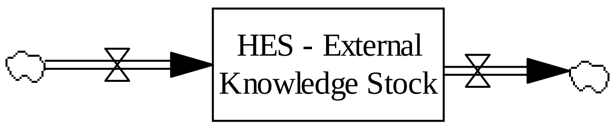
Figure 7-8 is a graphical representation of the data gathered that will be used as the rate at which the system absorbs new knowledge.

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 Unit: Researcher
	Cumulative years R&D experience of researchers Unit: Year

Stock	Quantification
	R&D output generated in the HES Unit: Papers
	Stock of absorbed knowledge is measured by counting the amount of foreign papers cited by scientists in the system Unit: Papers
	The stock of external knowledge is the amount of scientific publications created in the external environment 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 • Young • Experienced • Mature	 77% 11% 11%
Natural attrition percentage of cohorts • Young • Experienced • Mature	 5% 5% 5%
Initial for the HR stocks (1980) • Young • Experienced • Mature	 4120 2480 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.

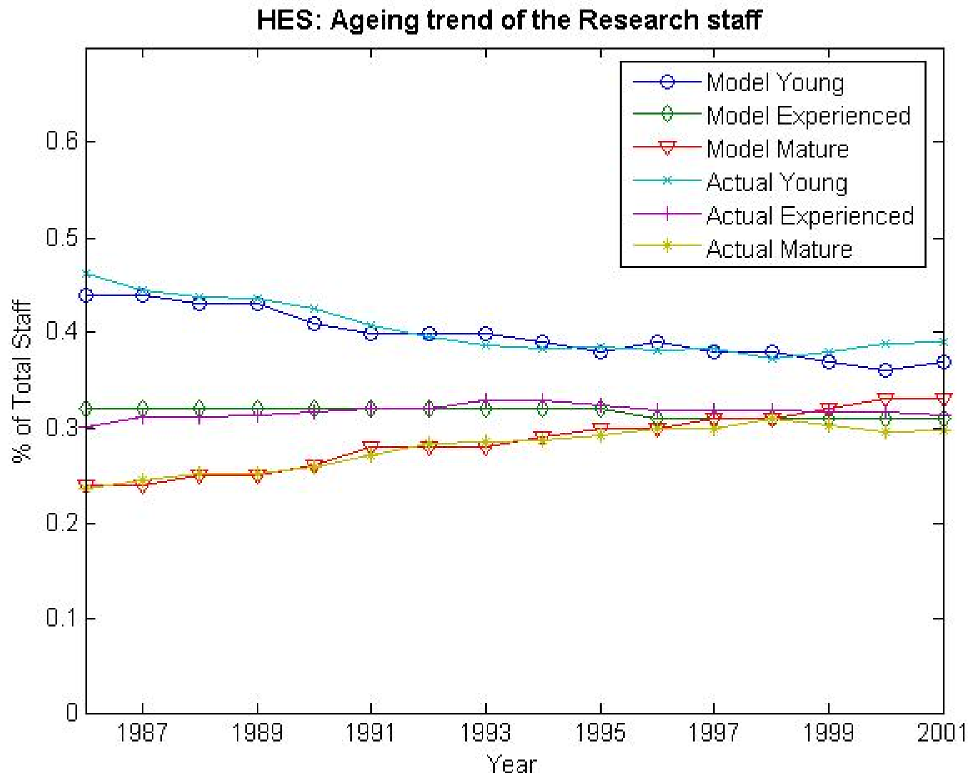


Figure 7-9: Model output recreating trend of the ageing of Scientific workforce.

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

                                     Sum of           Mean
Source                   DF         Squares         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

                              Parameter       Standard
    Variable         DF        Estimate          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.

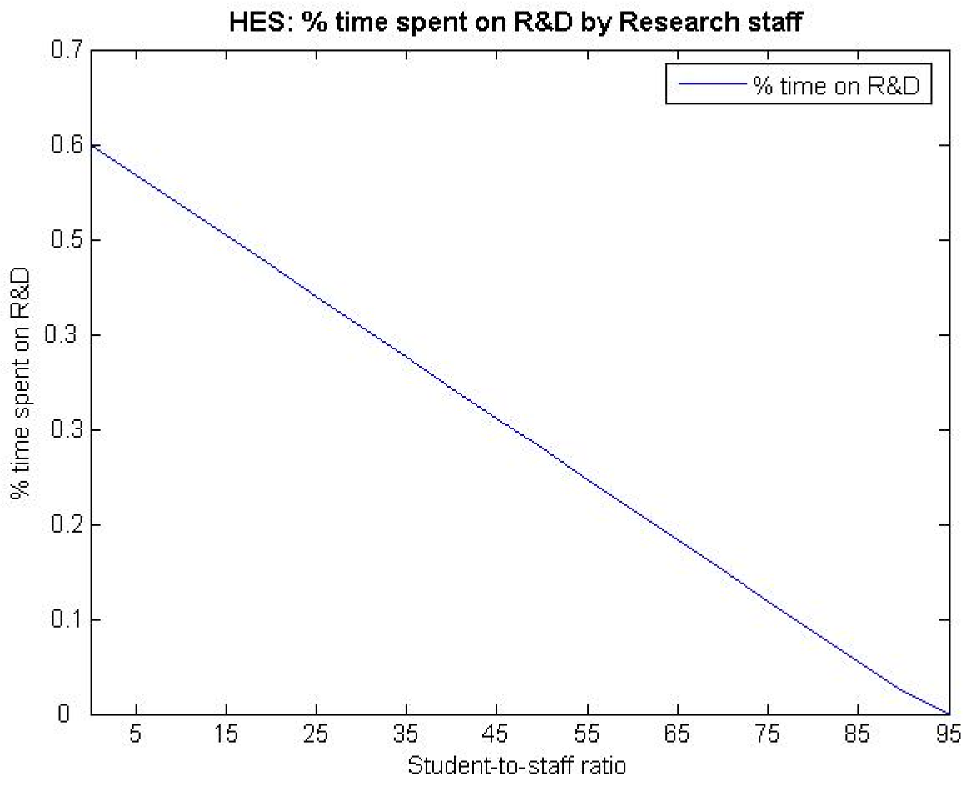


Figure 7-10: Relationship between Student-to-Staff ratio and Time Spent on R&D.

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.

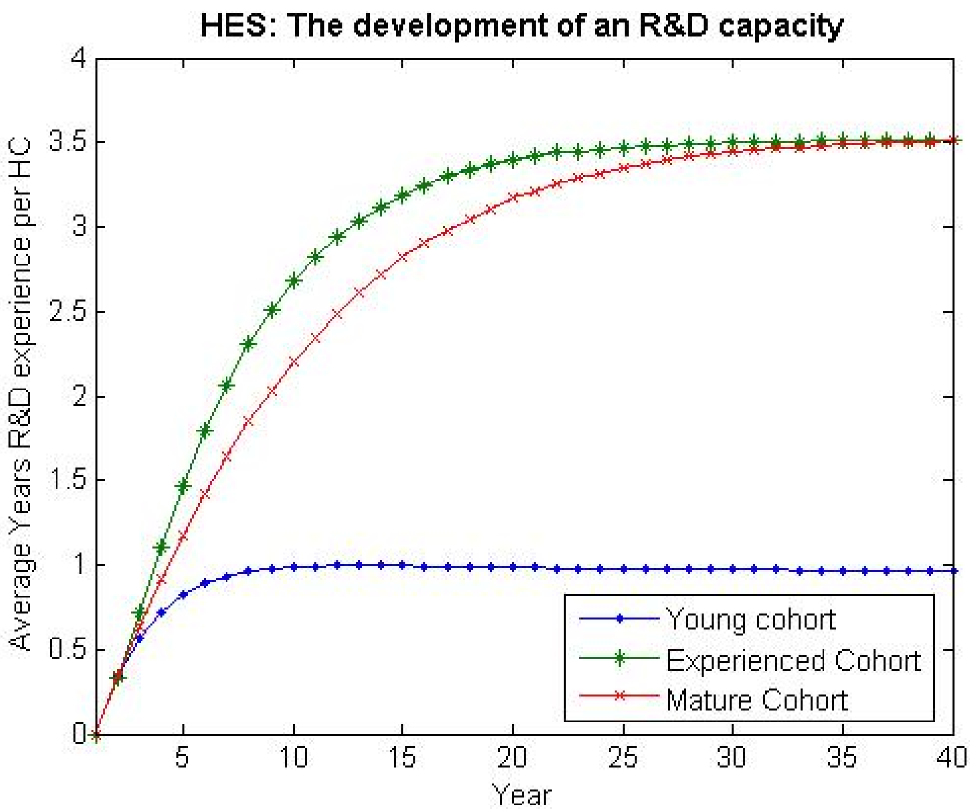


Figure 7-11 The Development of an R&D Capacity (Age Cohorts)

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).

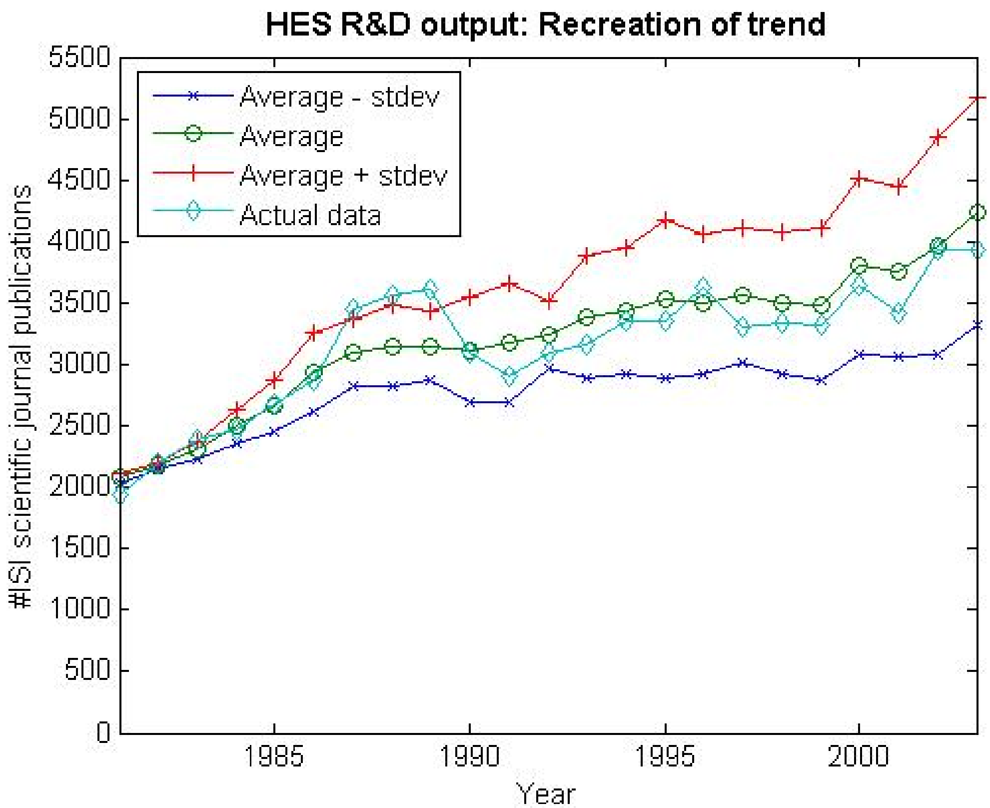


Figure 7-13: Model Recreation of the Production of Scientific Output

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:

$$\frac{R_{Absorptionr}}{R^{*}_{Absorption}} = f * \left(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutpu}} * \frac{S_{FTE}}{S^{*}_{FTE}}\right)^{d} * \left(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}}\right)^{e} \quad \textbf{7-7}$$

This expression is linearised by taking the log-linear form:

$$\ln\left(\frac{R_{Absorptionr}}{R^{*}_{Absorption}}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutpu}} * \frac{S_{FTE}}{S^{*}_{FTE}}\right) + e * \ln\left(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}}\right)$$

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:

$$\ln\left(\frac{R_{Absorptionr}}{R^{*}_{Absorption}}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S^{*}_{R\&Doutpu}} * \frac{S_{FTE}}{S^{*}_{FTE}}\right) + e * \ln\left(\frac{S_{World}}{S^{*}_{World}} / \frac{S_{HC}}{S^{*}_{HC}}\right) \quad \textbf{7-9}$$

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.

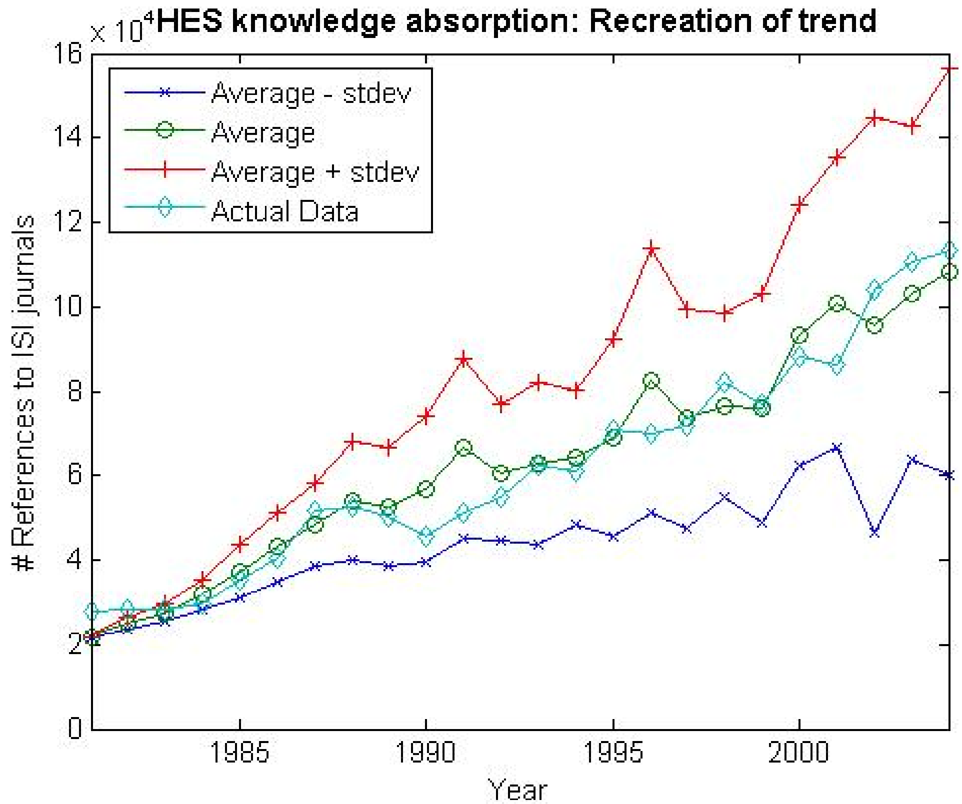


Figure 7-14: Model Recreation of the Absorption of Knowledge Trend Data

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.

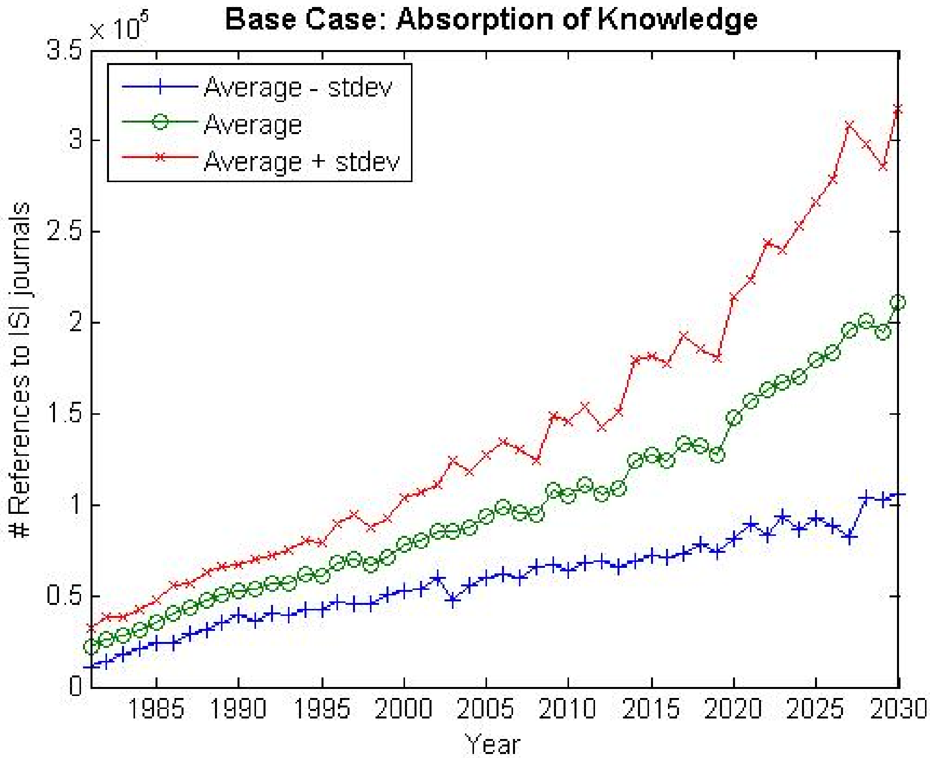


Figure 7-15: Output from the HES Model for Knowledge Absorption Rate

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.

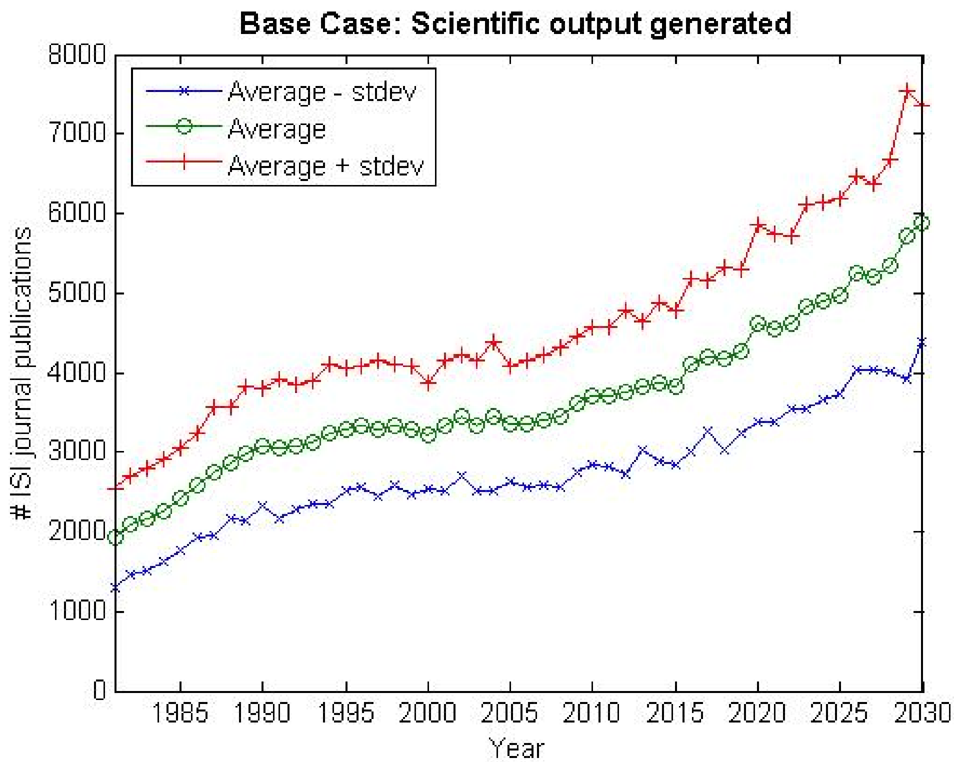


Figure 7-16: Output from the HES Model for Scientific Output Development Rate

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.

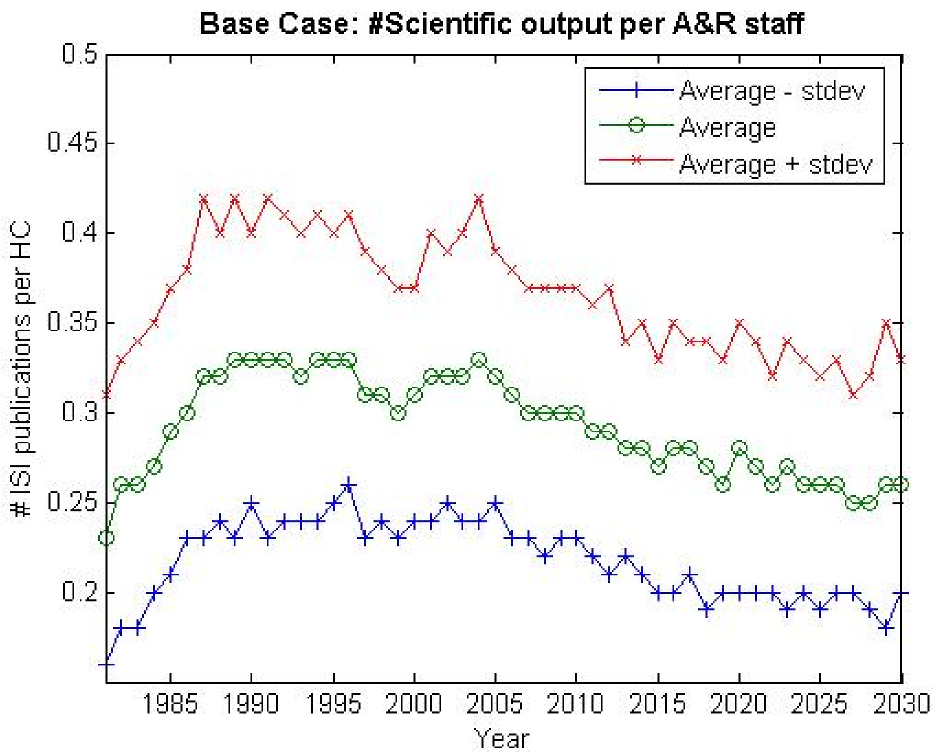


Figure 7-17: Paper Productivity per Headcount in the HES

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.

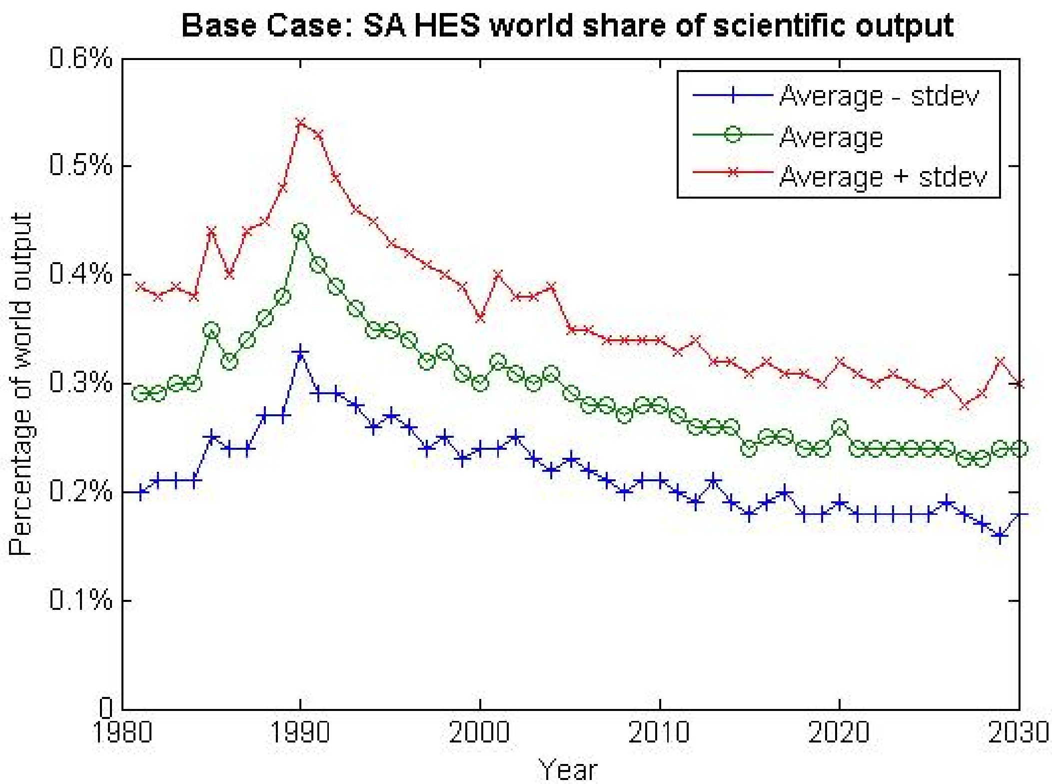


Figure 7-18: Base Case Model Output for the South African World Share of Publcations

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.

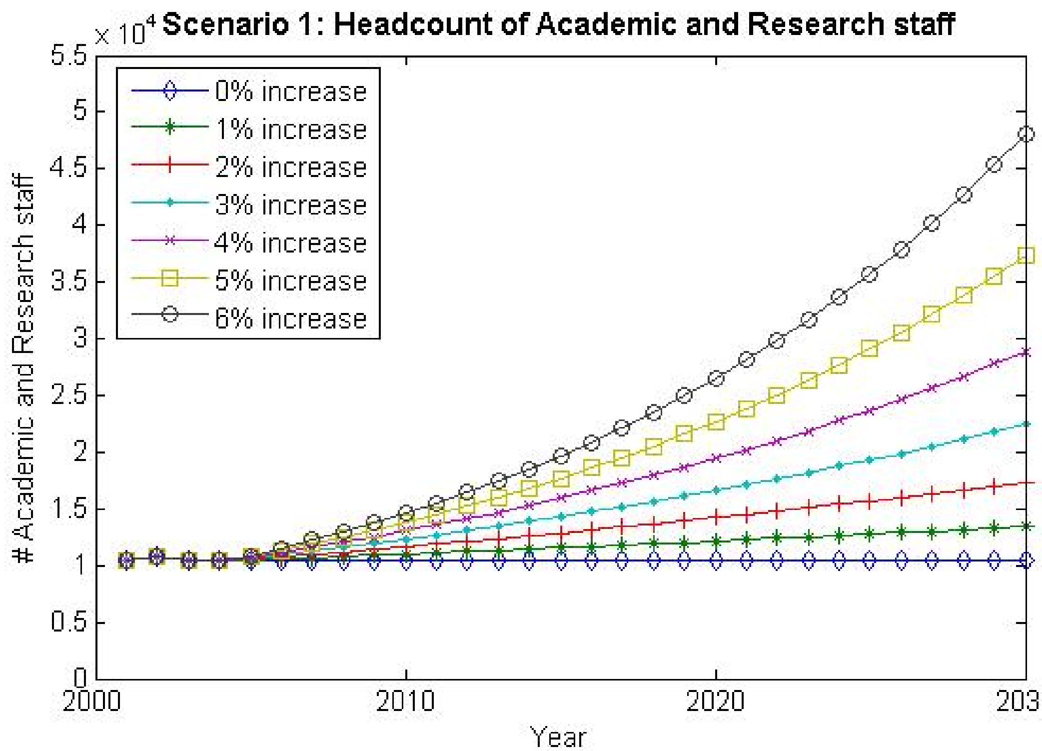


Figure 7-19: Academic and Research Personnel at Universities in South Africa

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.

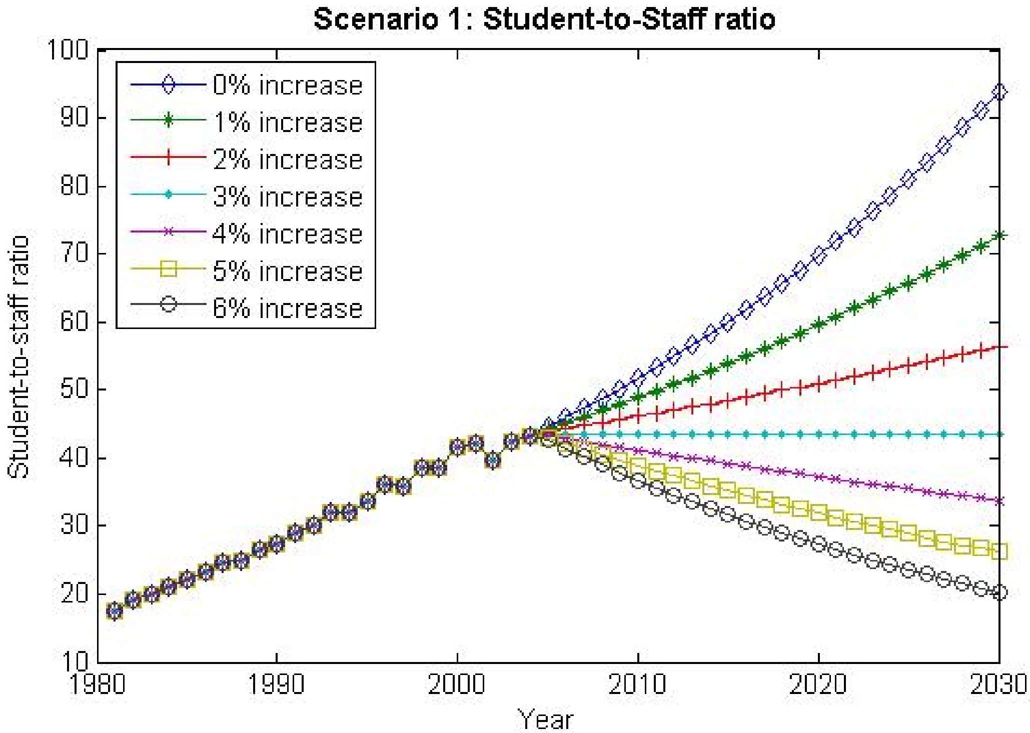


Figure 7-20: Scenario 1 - Student-to-Staff Relationship for the Simulation Runs

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.

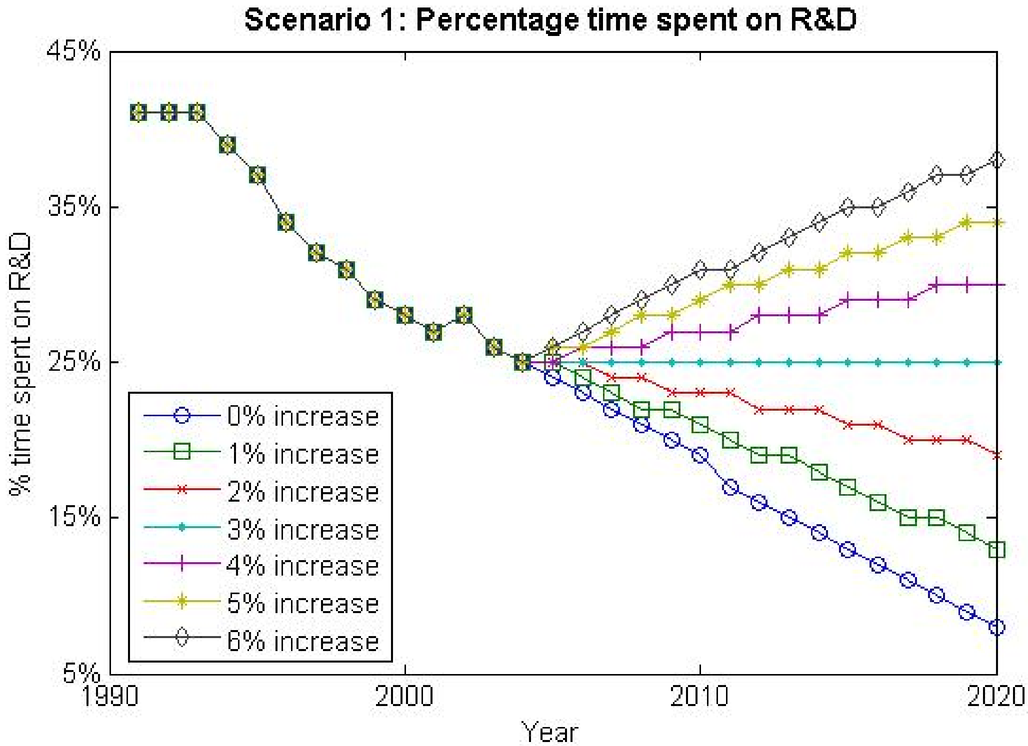


Figure 7-21: Percentage time spent on R&D Activities by Academic and Research Staff

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.

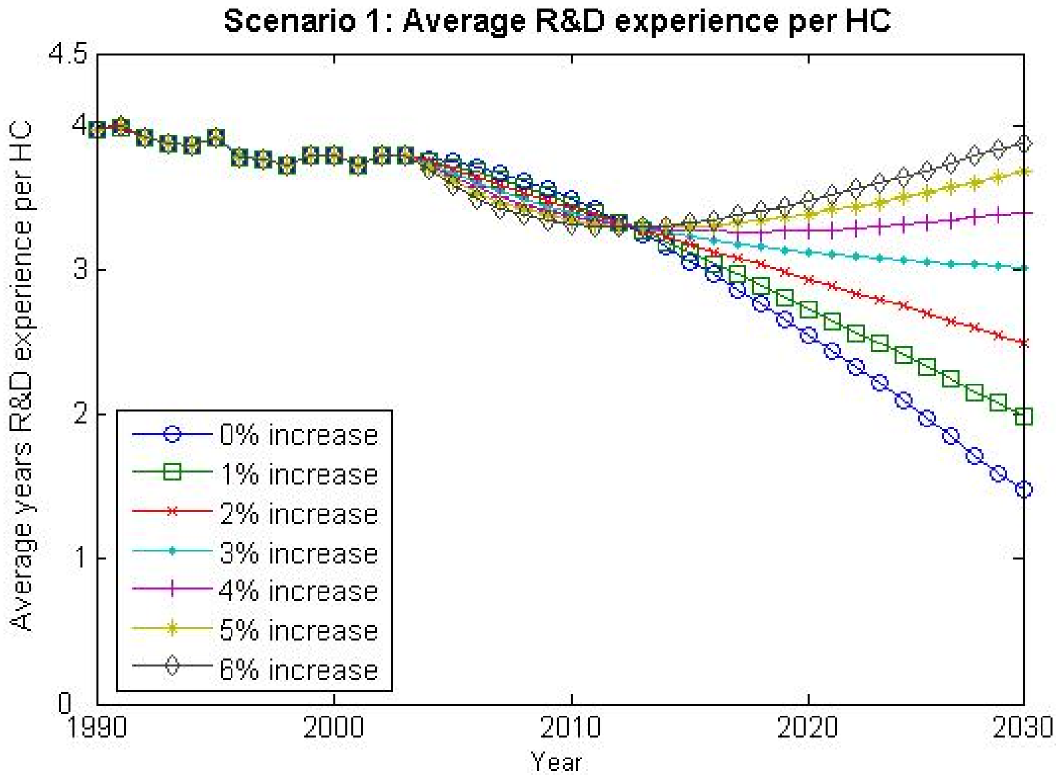


Figure 7-22: Scenario 1: Avg Experience in R&D per HC

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.

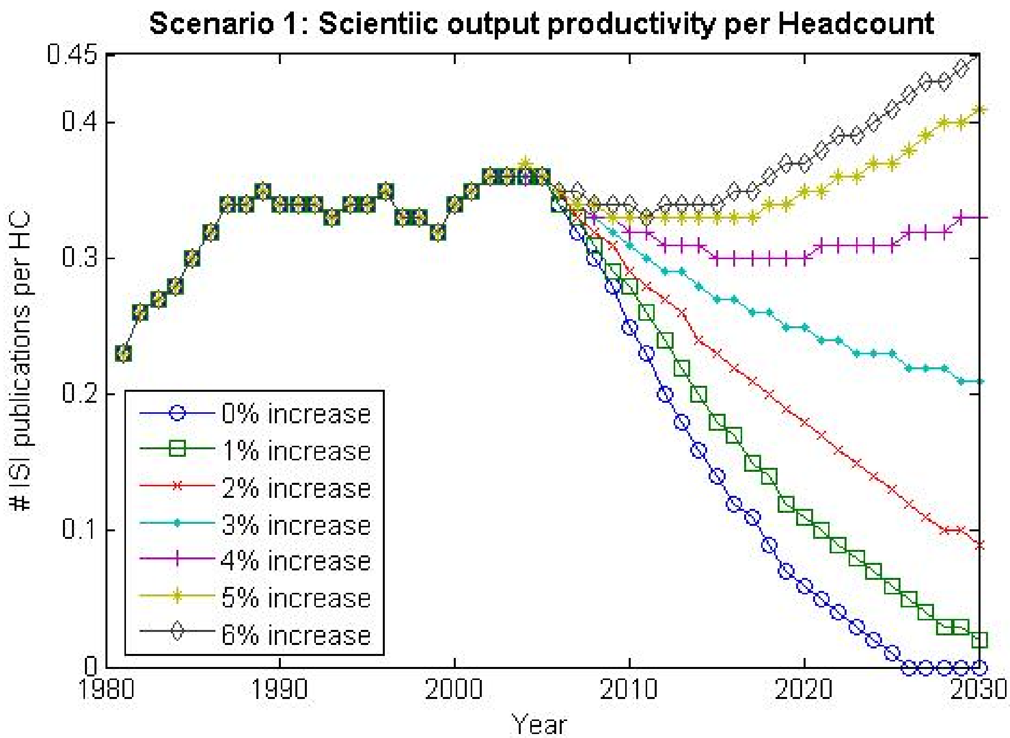


Figure 7-23: Scenario 1: Productivity per Headcount Employed in the System

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.

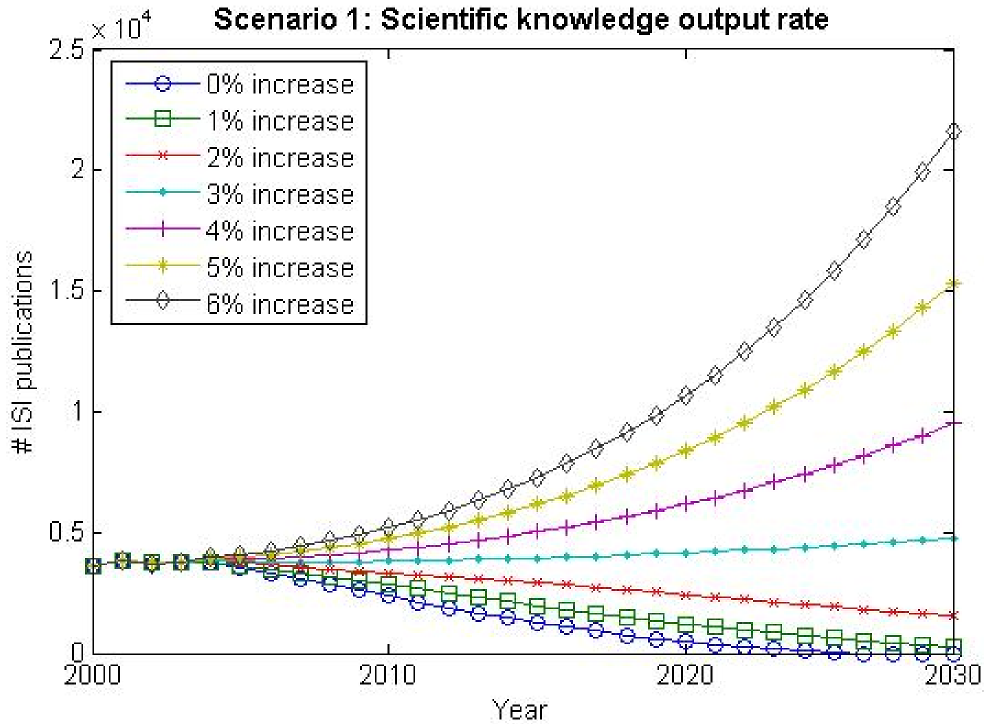


Figure 7-24: **Scenario 1: Rate at which new R&D Outputs are created in the HES**

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.

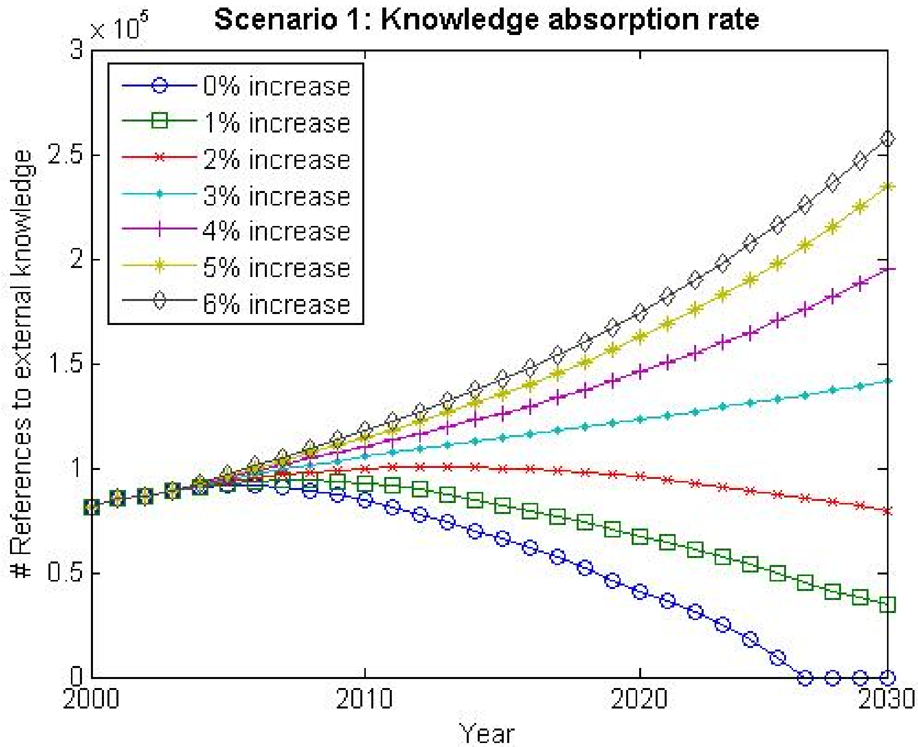


Figure 7-25: Scenario 1: Knowledge Absorption Rate

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.

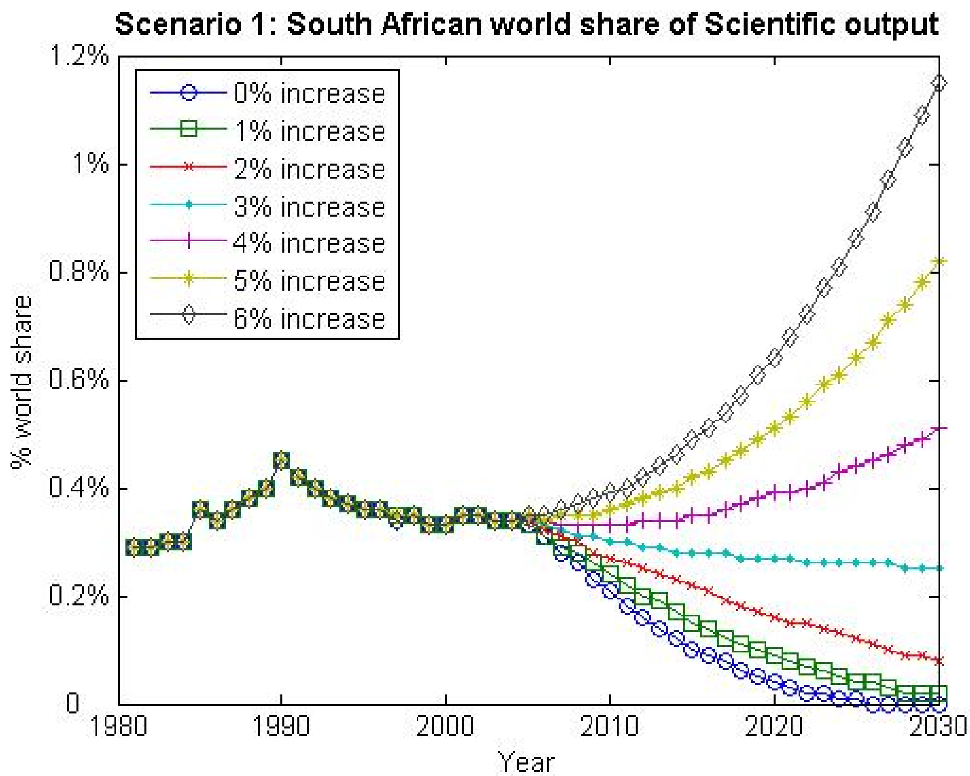


Figure 7-26: Scenario 1: Projected HES Share of Scientific Output in the World

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.

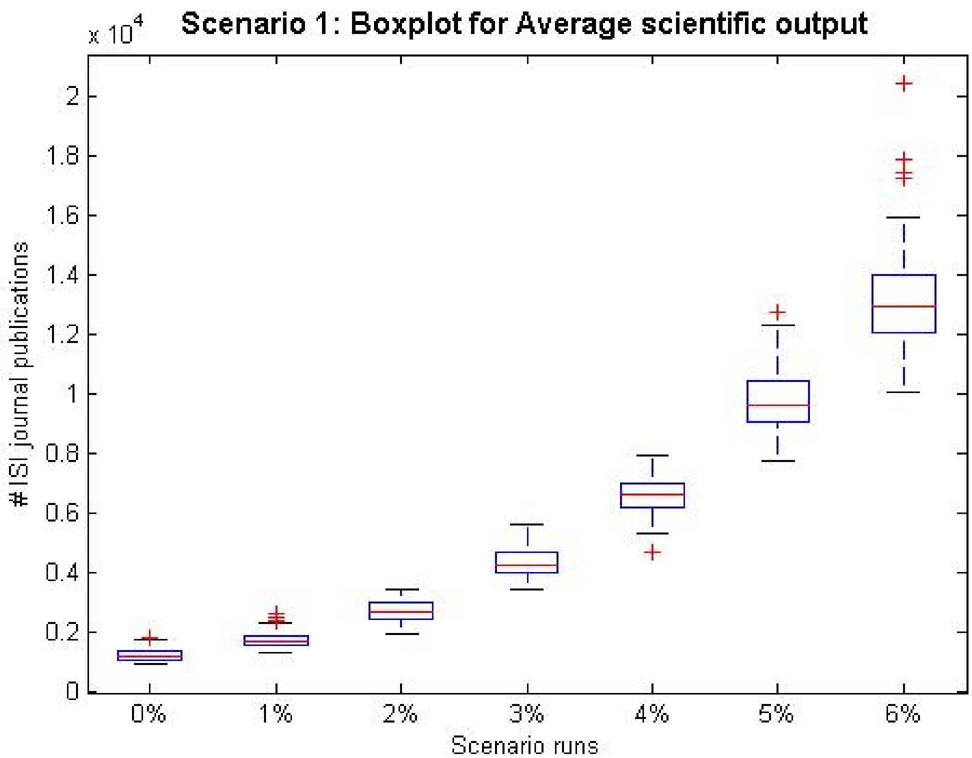


Figure 7-27: Scenario 1: Box Plot for Average Scientific Output Generated in the HES

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.

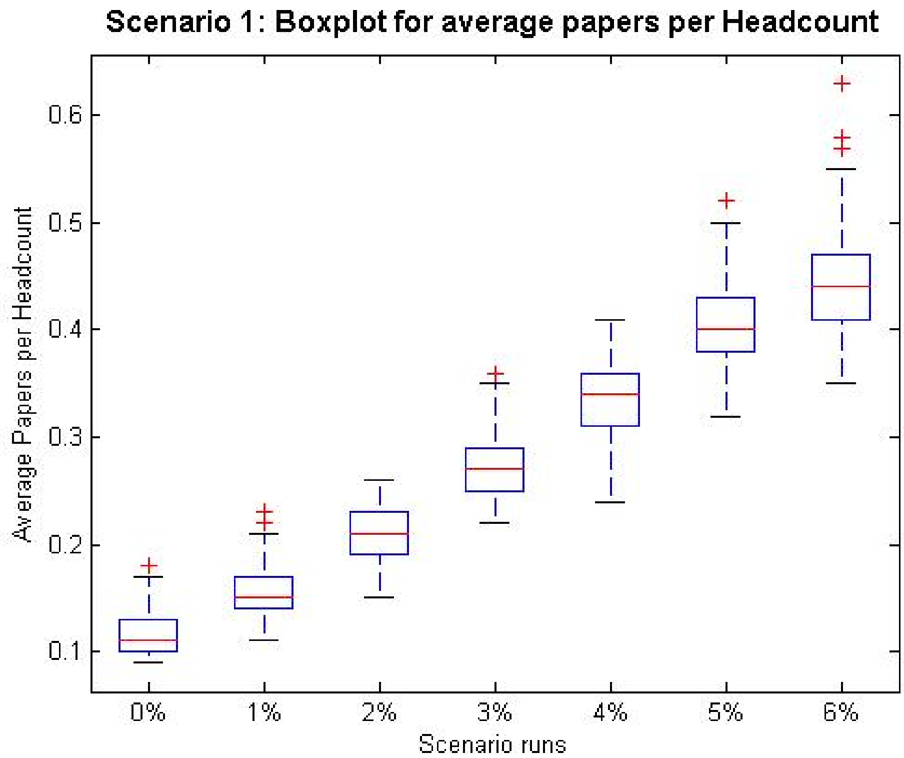


Figure 7-28: Scenario 1: Box Plot for the Average Paper per Headcount Generated

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.

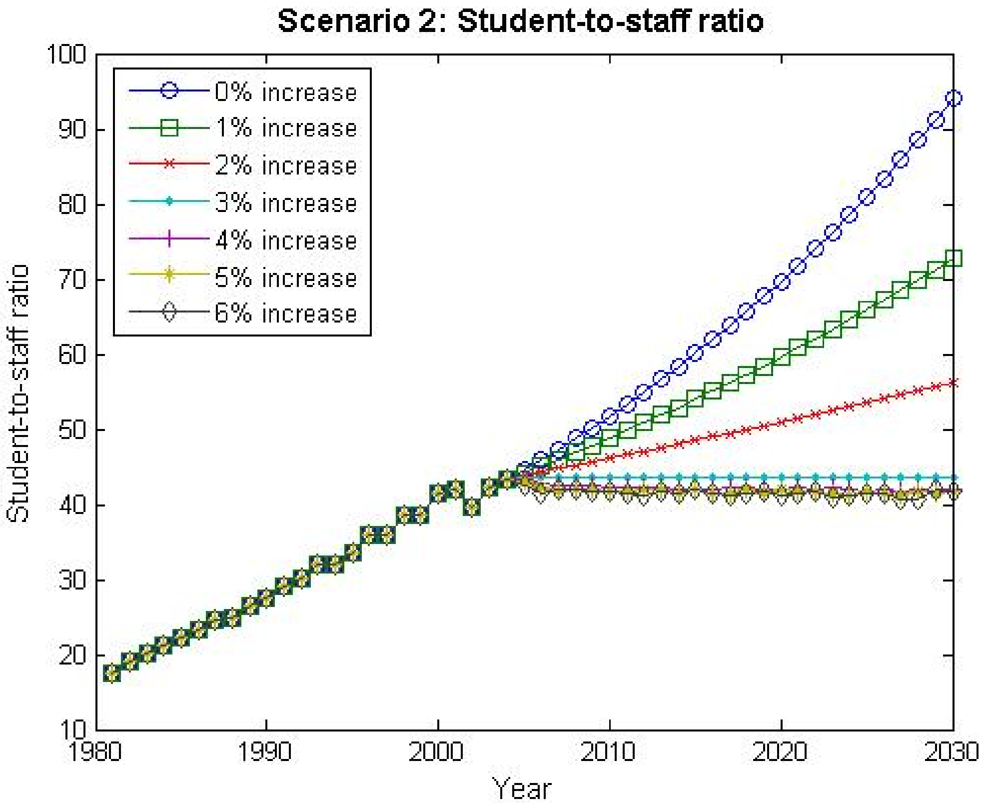


Figure 7-29: Scenario 2: Student-to-staff Ratio

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.

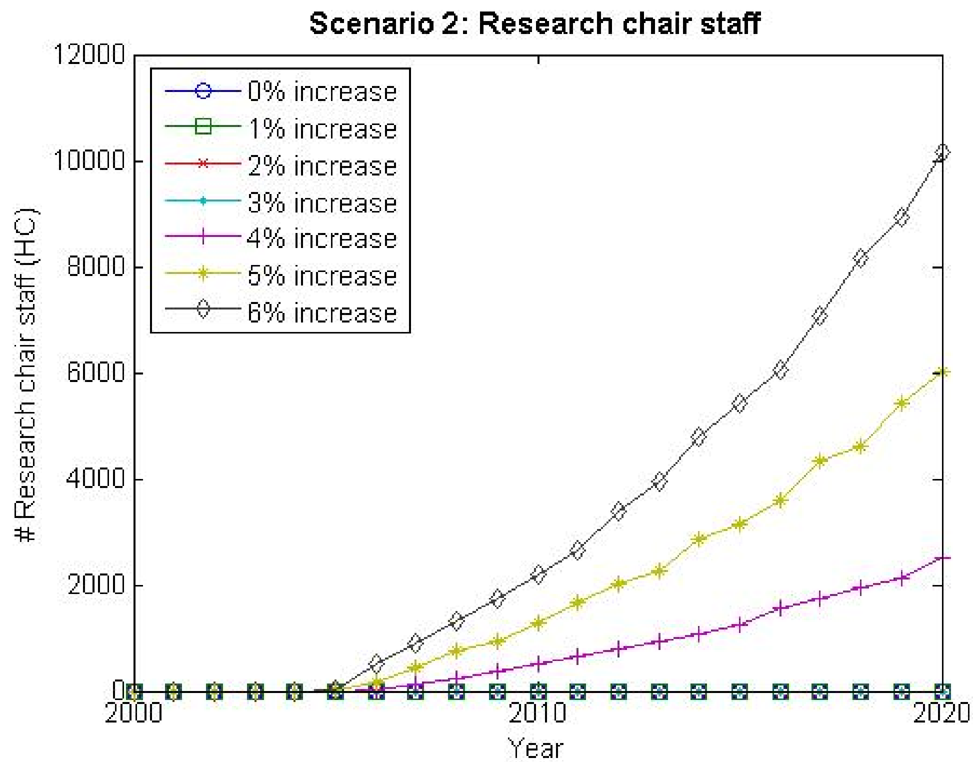


Figure 7-30: Scenario 2: Research Chair Positions in the South African HES

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.

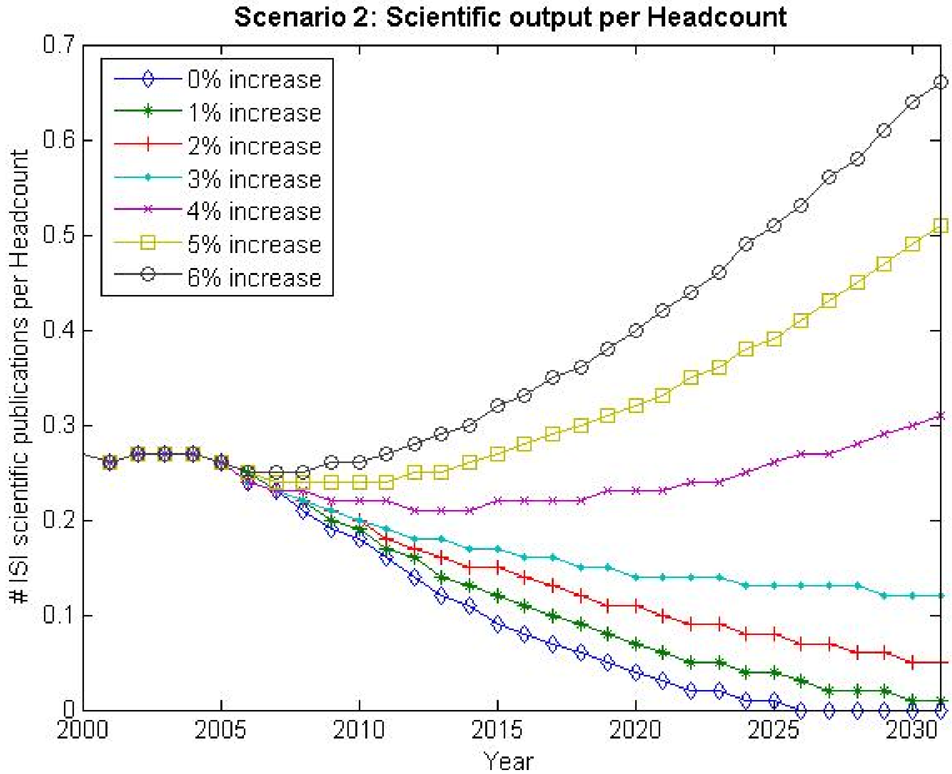


Figure 7-31: Scenario 2: Paper Productivity per Headcount Staff Employed in the System

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.

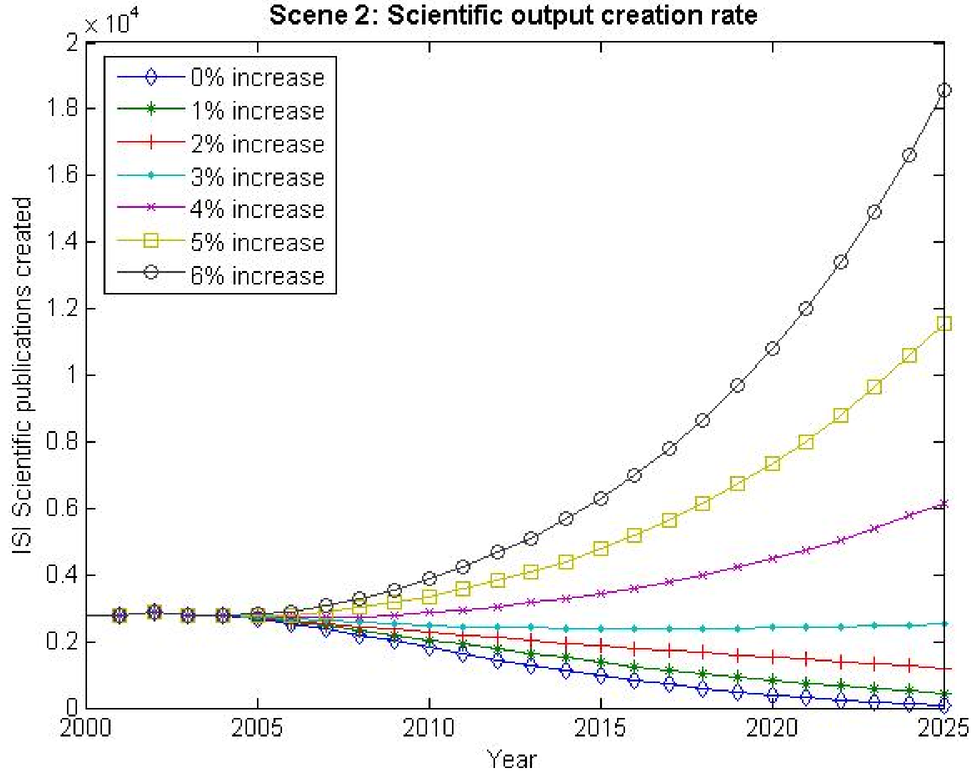


Figure 7-32: Scenario 2: The Ability of the System to Create New Knowledge

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.

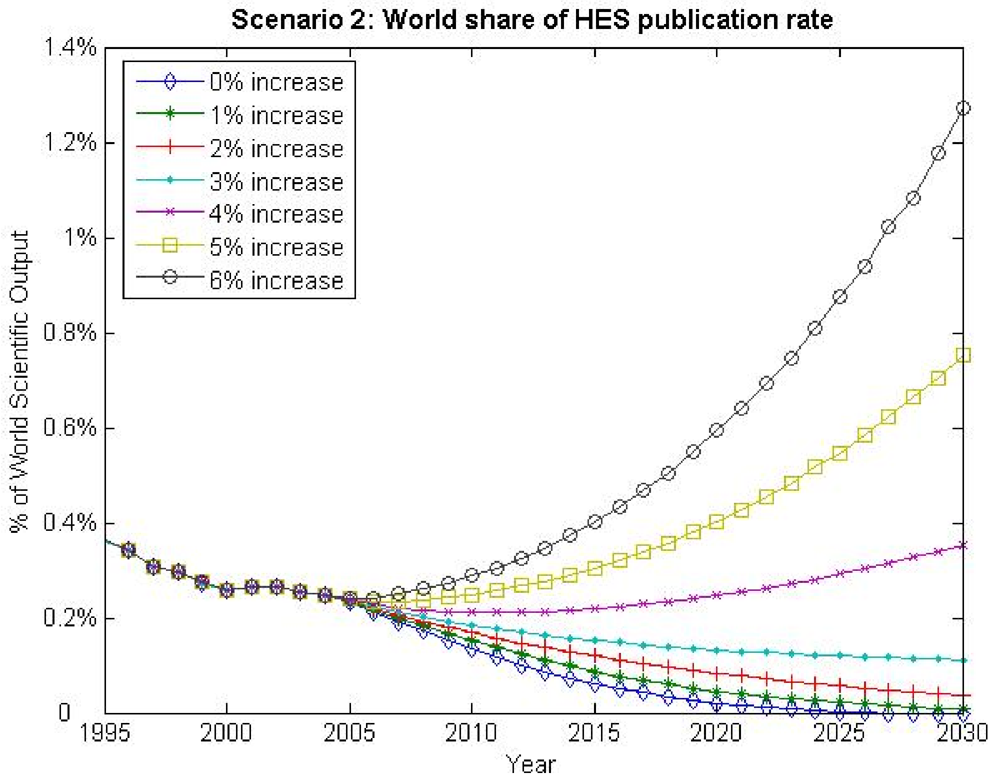


Figure 7-33: Scenario 2: The South African Share of Scientific Output

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.

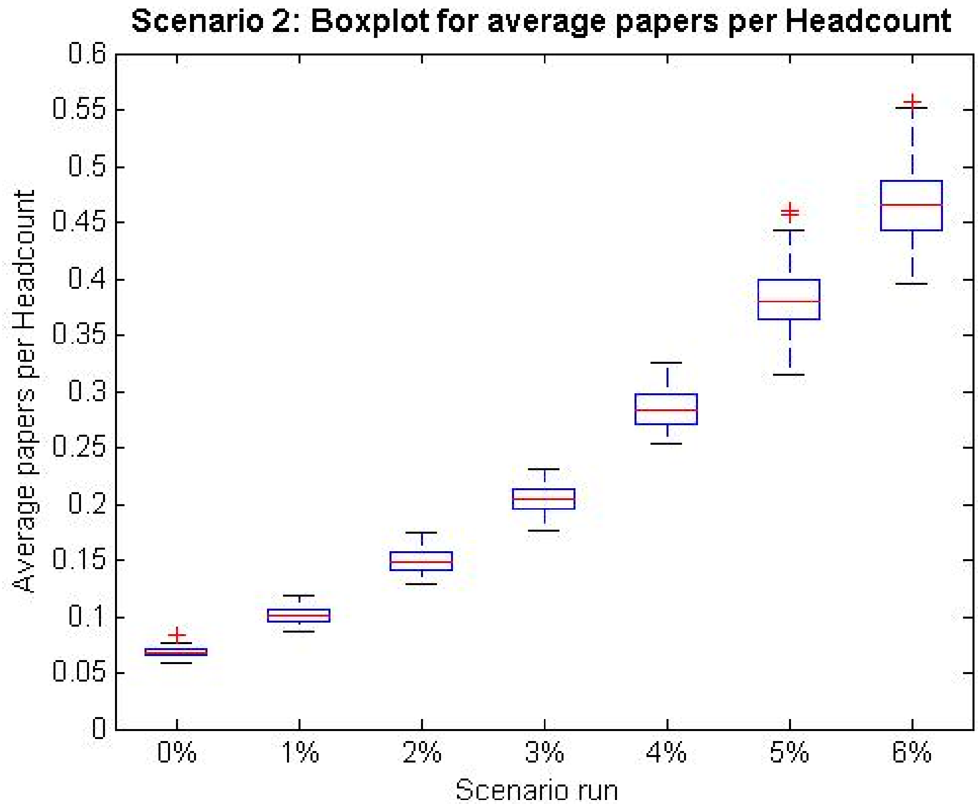


Figure 7-34: Scenario 2: Box Plot for Avg. Papers per Headcount Produced in the HES

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.

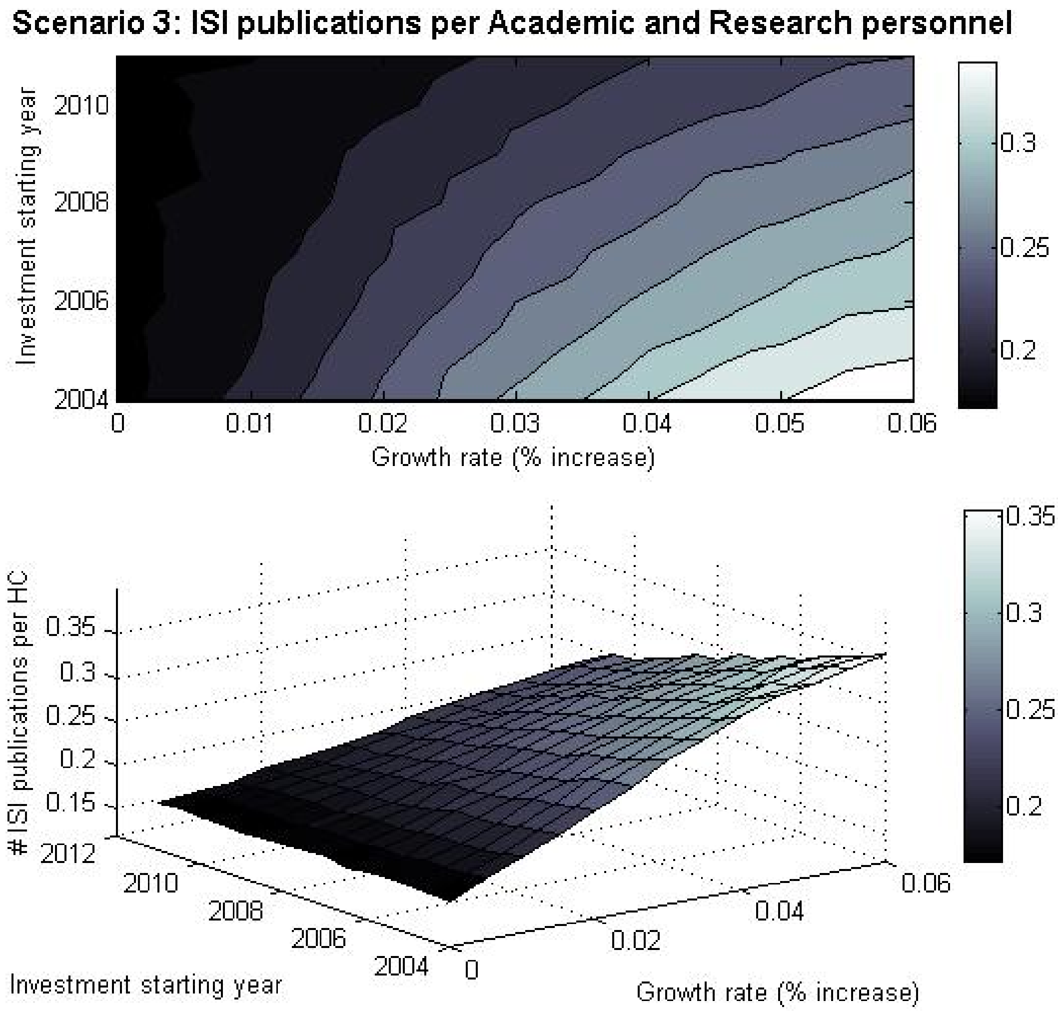


Figure 7-35: **Scenario 3: ISI Publications per Academic and Research Personnel**

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.

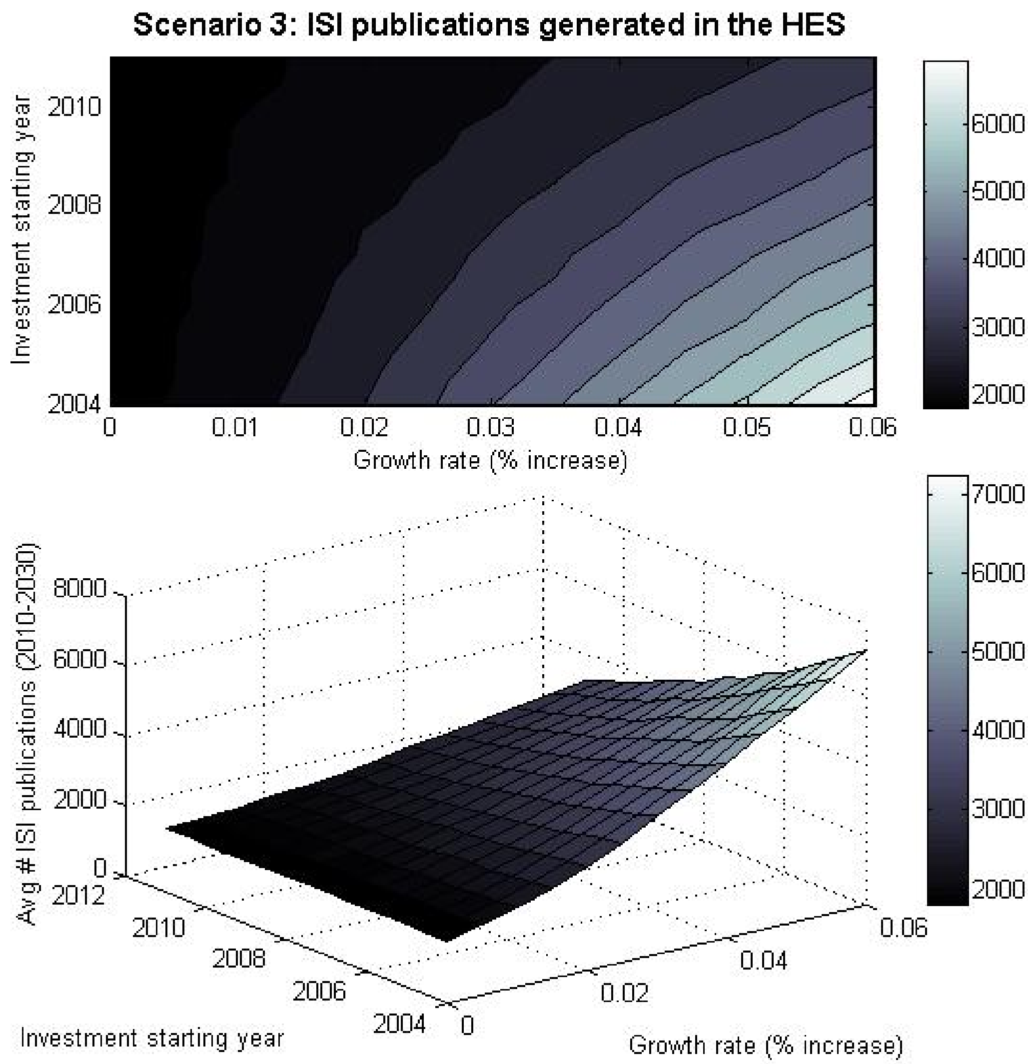


Figure 7-36: Scenario 3: ISI Publications Generated in the HES

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:

$$\%Time\_on\_R\&D = 0.58592 + (-0.16677) * (1 - \%improvement) * \frac{StudentStaff\ Relationship}{StudentStaff\ Relationship^{*}}$$

Where $StudentStaff\ Relationship^{*} = 26.15$ **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.

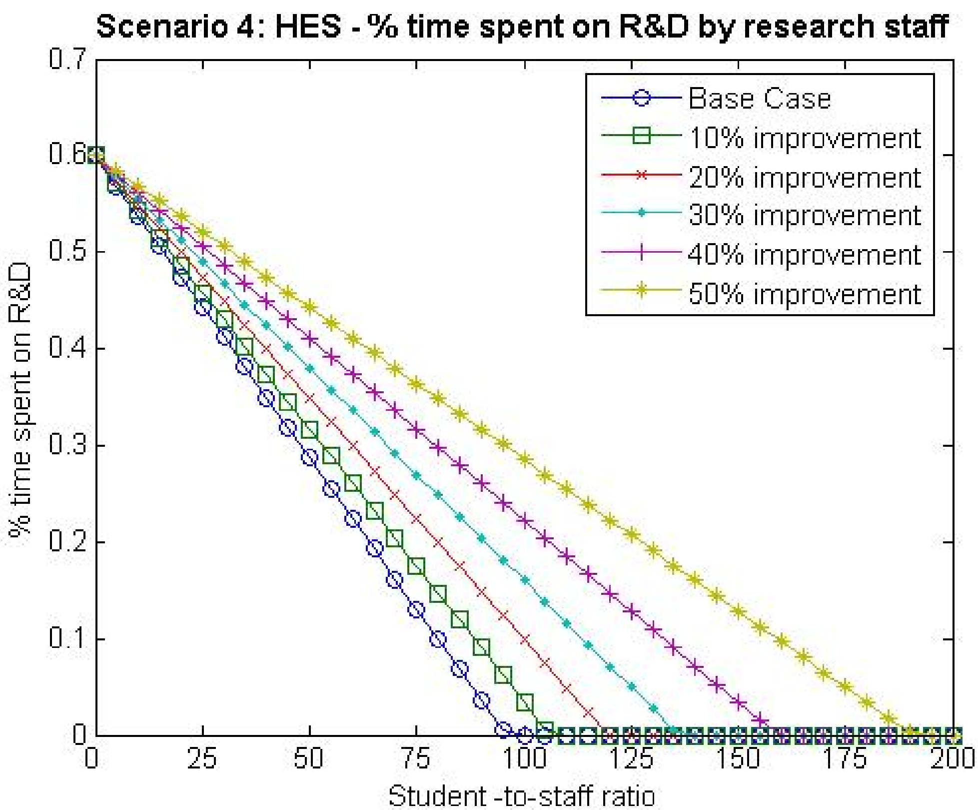


Figure 7-37: Scenario 4: Effect of % improvement on time spent on R&D

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.

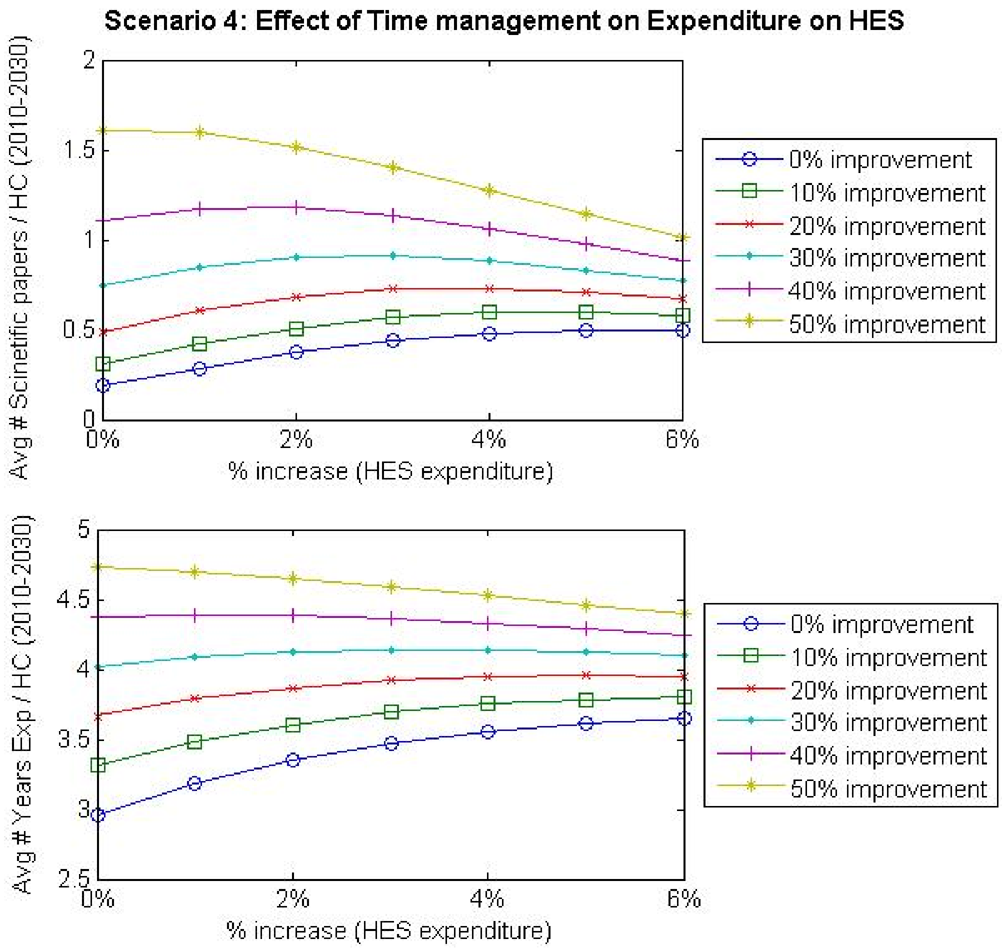


Figure 7-38: Scenario 4: Papers Produced per Headcount on the HES

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.

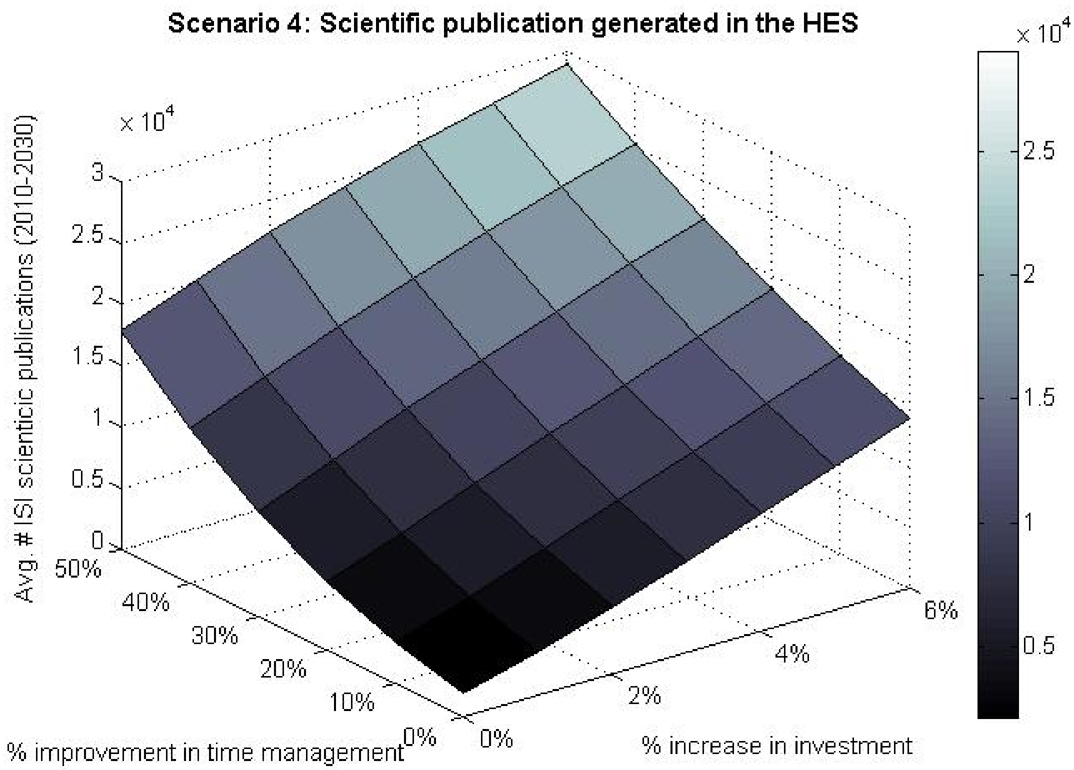


Figure 7-39: Scenario 4: ISI Scientific Publications Generated in the HES

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.