

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 found.

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 - Expenditure on technicians - 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.

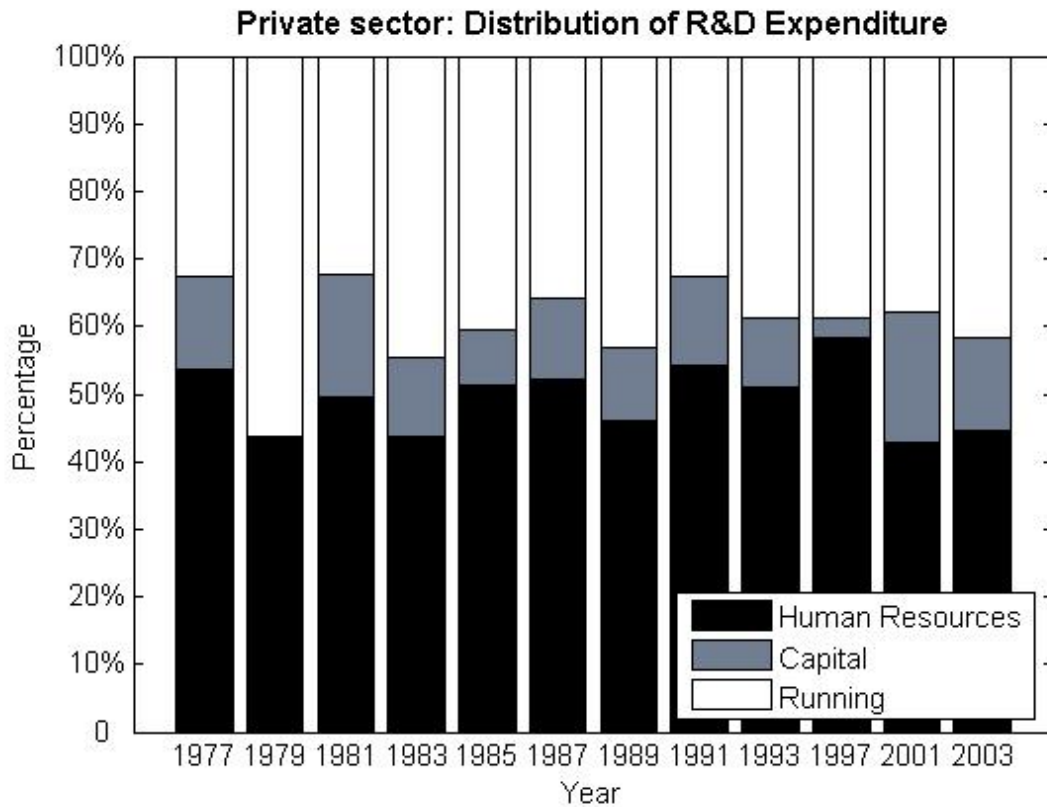


Figure 9-1: Private Sector: Distribution of R&D Expenditure

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.

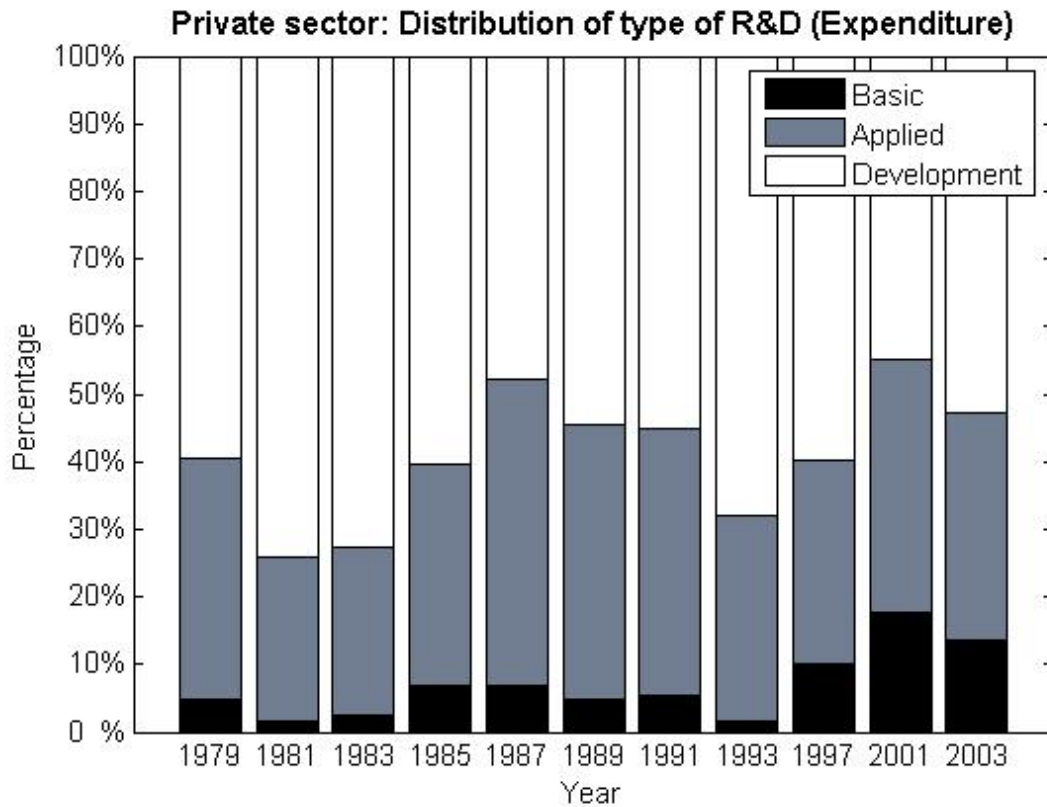


Figure 9-2: Private Sector: Distribution of Type of Research (Expenditure)

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	6.6%	5.2%
Percentage expenditure on applied research	34.4%	6.7%
Percentage expenditure on experimental development	59%	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.

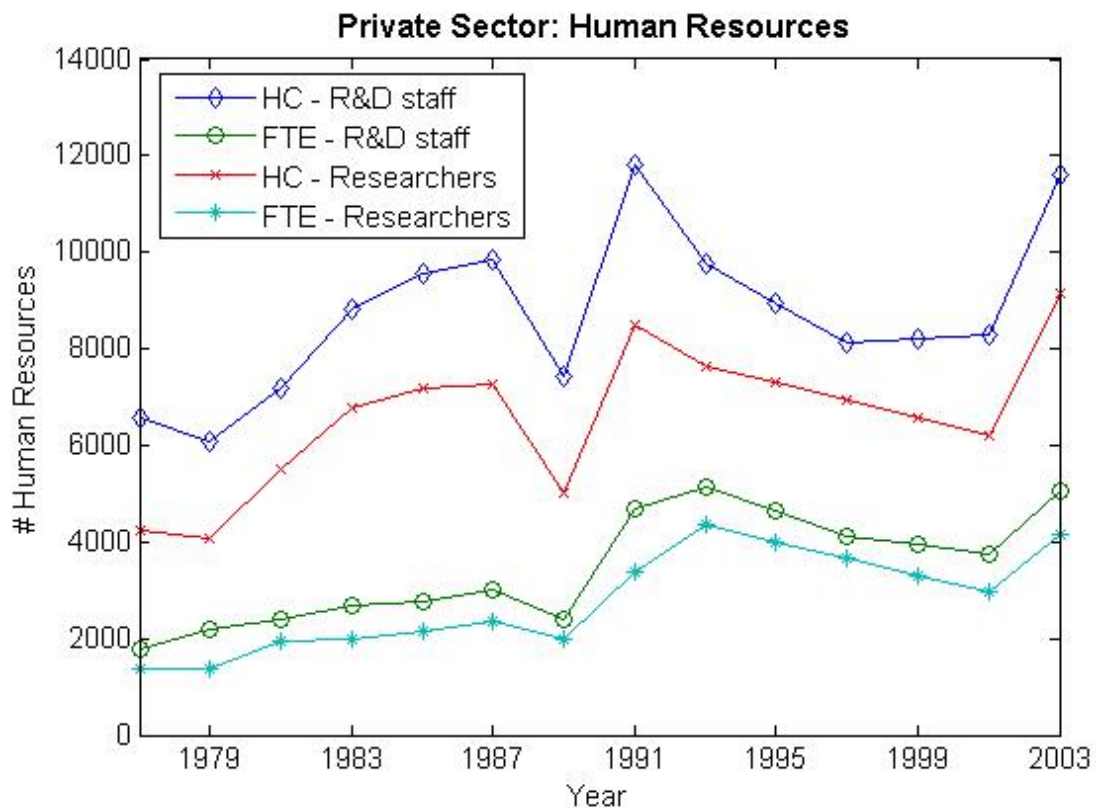


Figure 9-3 R&D Human Resources in the Private sector

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.**).

Patent counts are a good measure of R&D output in the SA Private Sector

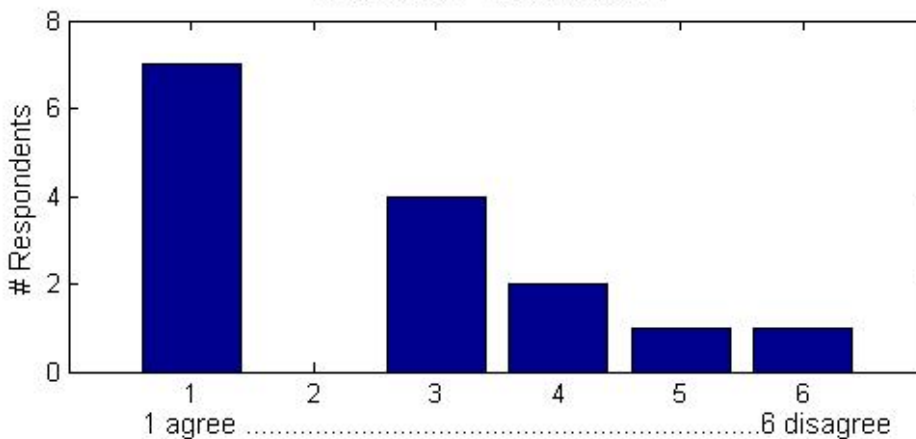


Figure 9-4: Patents counts as a measure of R&D output created in the Private sector

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.

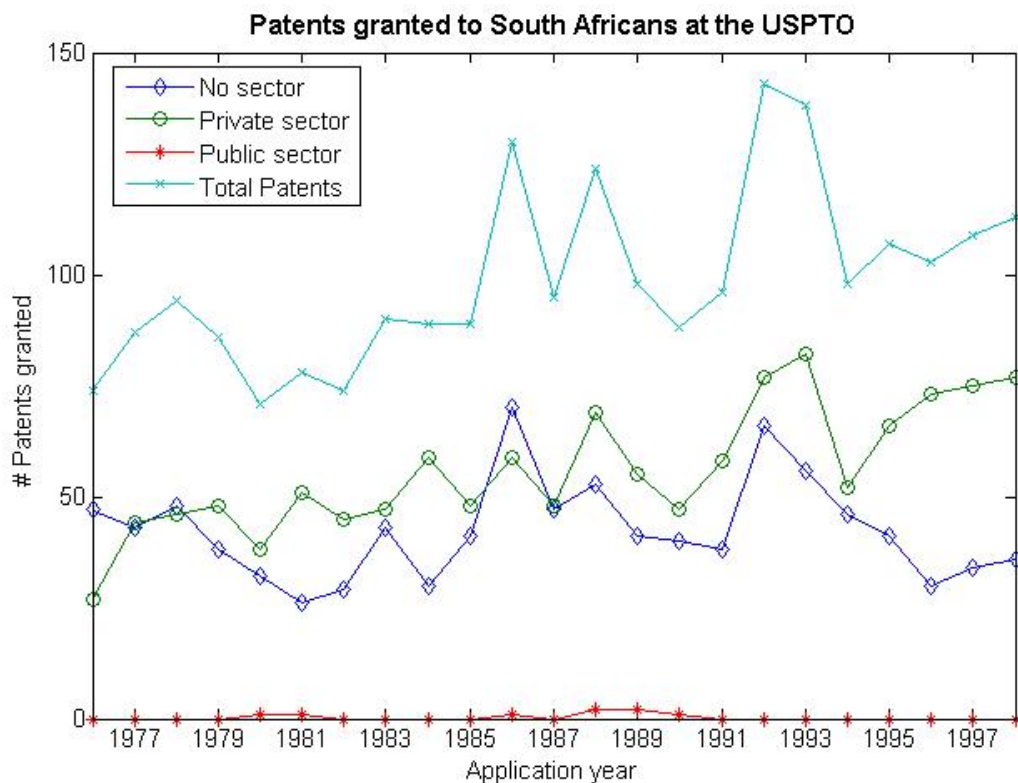


Figure 9-5 Scientific output generated in the South African Private sector

Data obtained from 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.

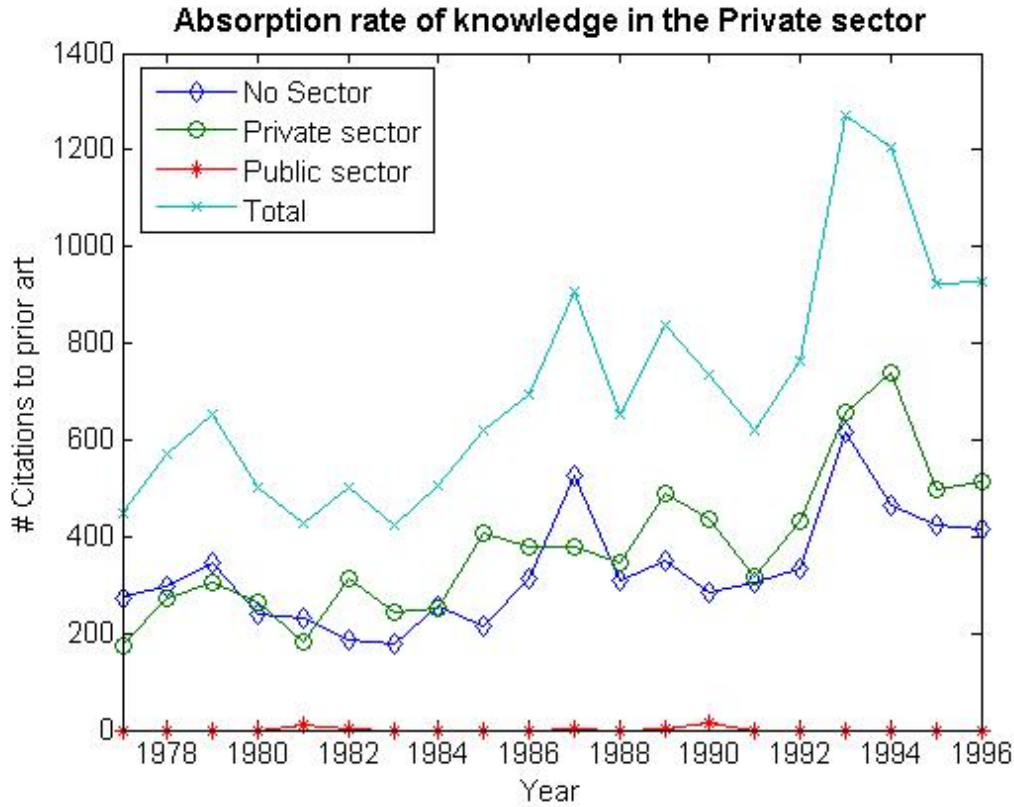



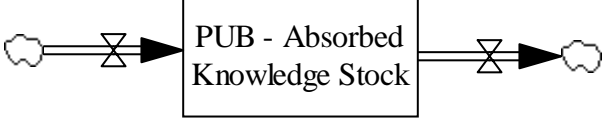
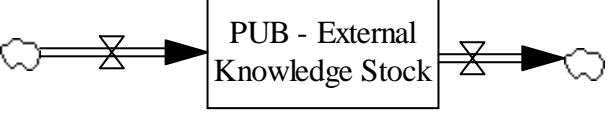
Figure 9-6. Number of references made to knowledge created in an external environment.

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
<p>PUB - Human Resources Stock</p>	Headcount – research personnel employed in the system Unit: Research personnel
<p>PUB - Human Knowledge Stock</p>	Cumulative years experience of researchers 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:	
• young	77%
• experienced	11%
• mature	11%
Natural attrition percentage of cohorts:	
• young	5%
• experienced	5%
• mature	5%
Initial for the human resource stocks (1980):	Total:
• young	2815
• experienced	1876
• mature	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.

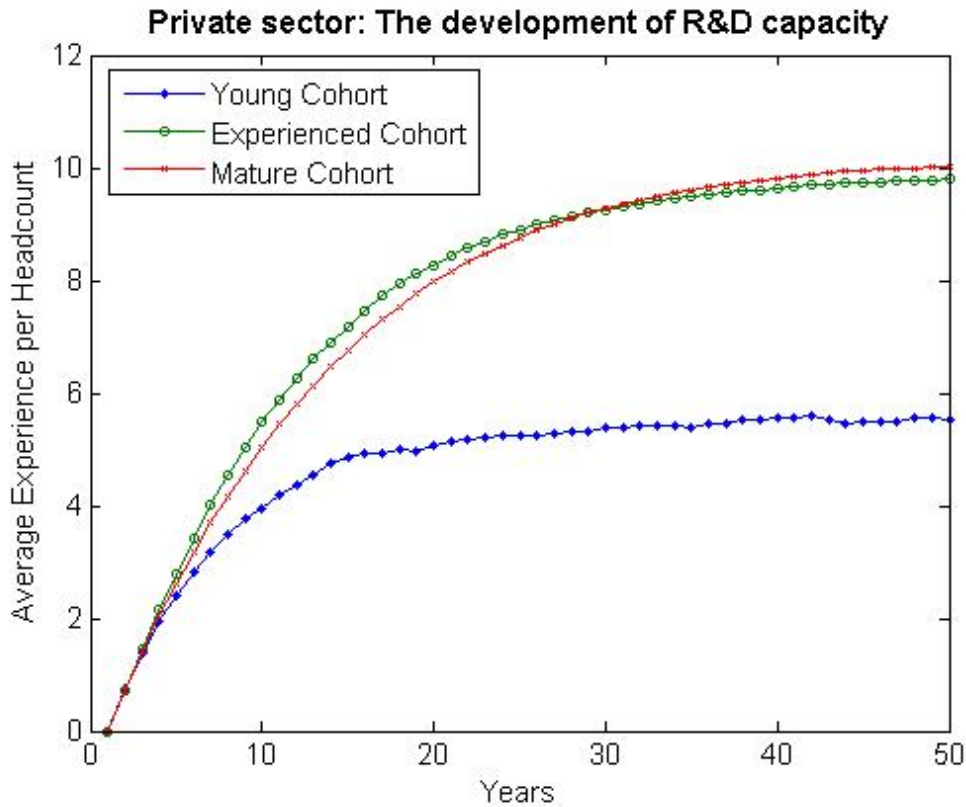


Figure 9-7 The Development of an R&D capacity (Age Cohorts)

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
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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:

$$\frac{R_{Paper}}{R_{Paper}^*} \cdot \frac{S_{FTE}}{S_{FTE}^*} = c * \left(\frac{S_{Experience}}{S_{Experience}^*} \cdot \frac{S_{HC}}{S_{HC}^*} \right)^a * \left(\frac{S_{Absorbed}}{S_{Absorbed}^*} \cdot \frac{S_{HC}}{S_{HC}^*} \right)^b \tag{9-1}$$

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

$$\ln\left(\frac{R_{Paper}}{R_{Paper}^*} \cdot \frac{S_{FTE}}{S_{FTE}^*}\right) = \ln(c) + a * \ln\left(\frac{S_{Experience}}{S_{Experience}^*} \cdot \frac{S_{HC}}{S_{HC}^*}\right) + b * \ln\left(\frac{S_{Absorbed}}{S_{Absorbed}^*} \cdot \frac{S_{HC}}{S_{HC}^*}\right) \tag{9-2}$$

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)
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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):

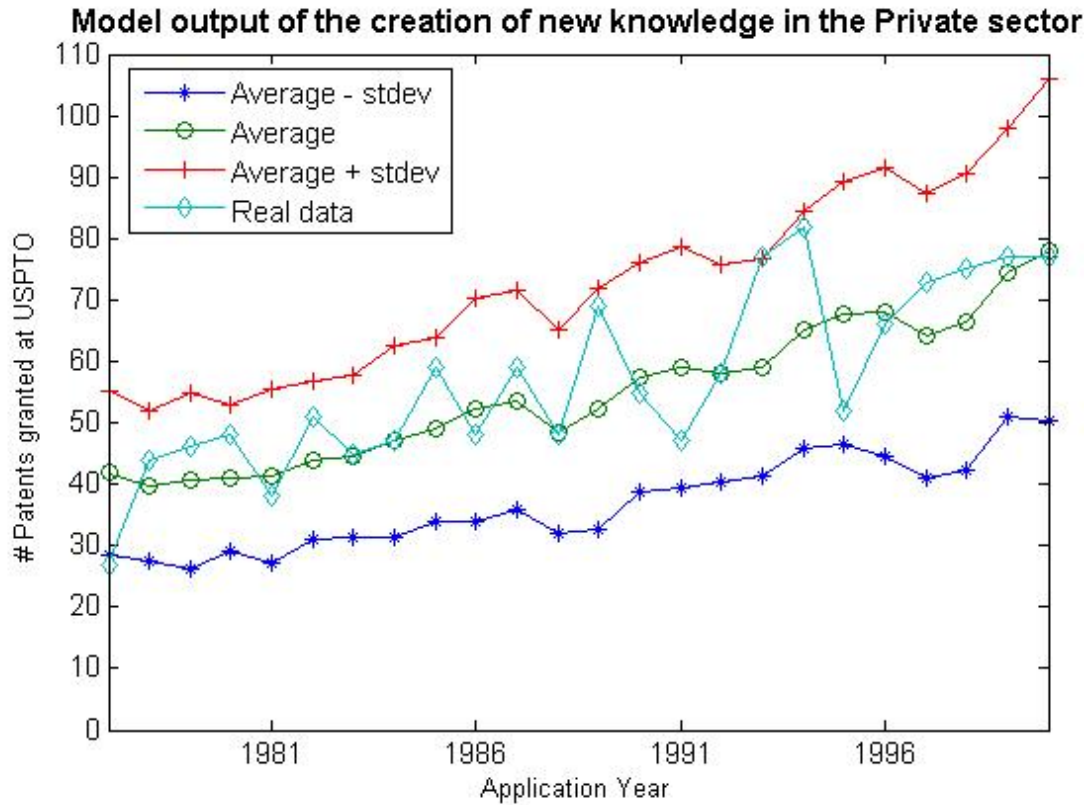


Figure 9-8: Model Output of the Creation of Knowledge Trend Data

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 exist 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:

- $R_{Absorption}$: 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:

$$\frac{R_{Absorptionr}}{R_{Absorption}^*} = f * \left(\frac{S_{R\&Doutput}}{S_{R\&Doutpu}^*} * \frac{S_{FTE}}{S_{FTE}^*} \right)^d * \left(\frac{S_{World}}{S_{World}^*} / \frac{S_{HC}}{S_{HC}^*} \right)^e \tag{9-3}$$

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

$$\ln\left(\frac{R_{Absorptionr}}{R_{Absorption}^*}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S_{R\&Doutpu}^*} * \frac{S_{FTE}}{S_{FTE}^*}\right) + e * \ln\left(\frac{S_{World}}{S_{World}^*} / \frac{S_{HC}}{S_{HC}^*}\right) \tag{9-4}$$

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							
Source	DF	Sum of Squares	Mean 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							
Variable	DF	Parameter Estimate	Standard 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
wspcrhc	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			

Variable	DF	Estimate	Standard Error	t Value	Approx 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:

$$\ln\left(\frac{R_{Absorptionr}}{R_{Absorption}^*}\right) = f + d * \ln\left(\frac{S_{R\&Doutput}}{S_{R\&Doutpu}^*} * \frac{S_{FTE}}{S_{FTE}^*}\right) + e * \ln\left(\frac{S_{World}}{S_{World}^*} / \frac{S_{HC}}{S_{HC}^*}\right) \quad 9-5$$

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.

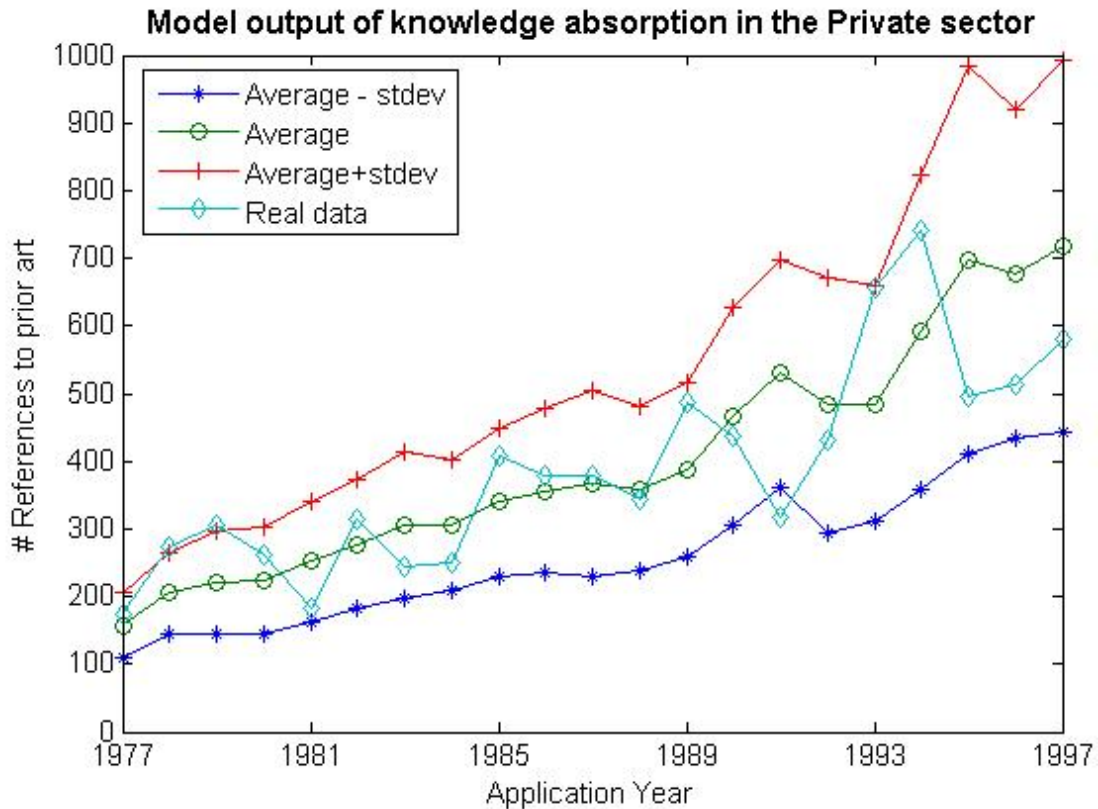


Figure 9-9: Model Recreation of the Absorption of Knowledge Trend Data

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?

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?

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.

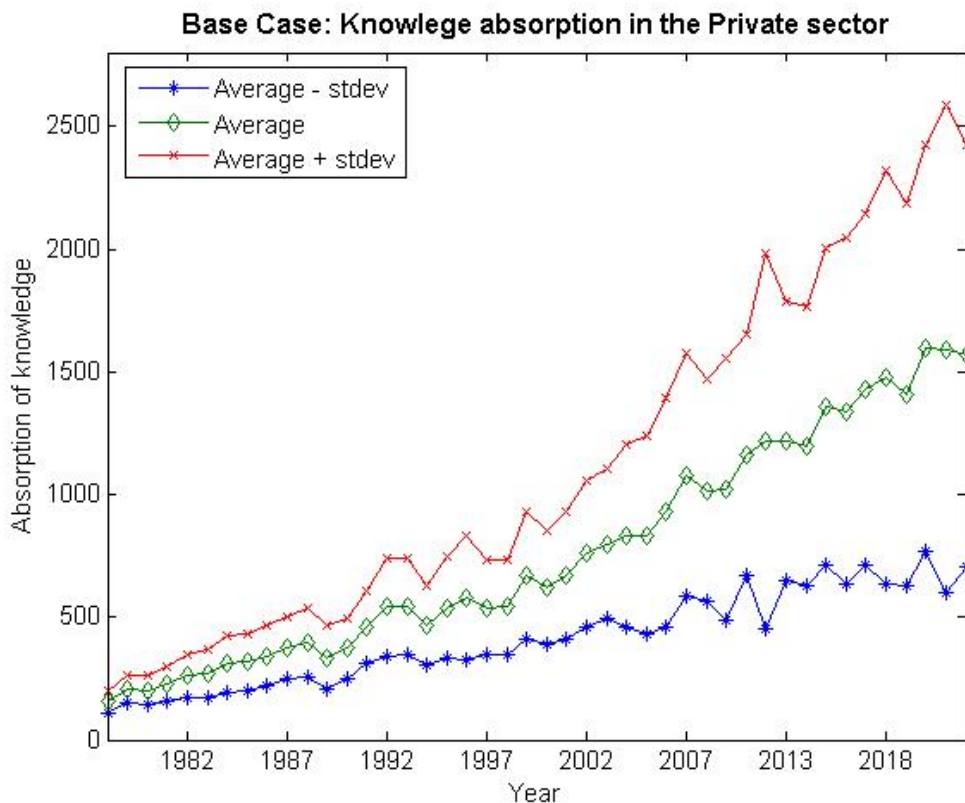


Figure 9-10 Absorption of Knowledge in the Private Sector under Base Case Conditions

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.

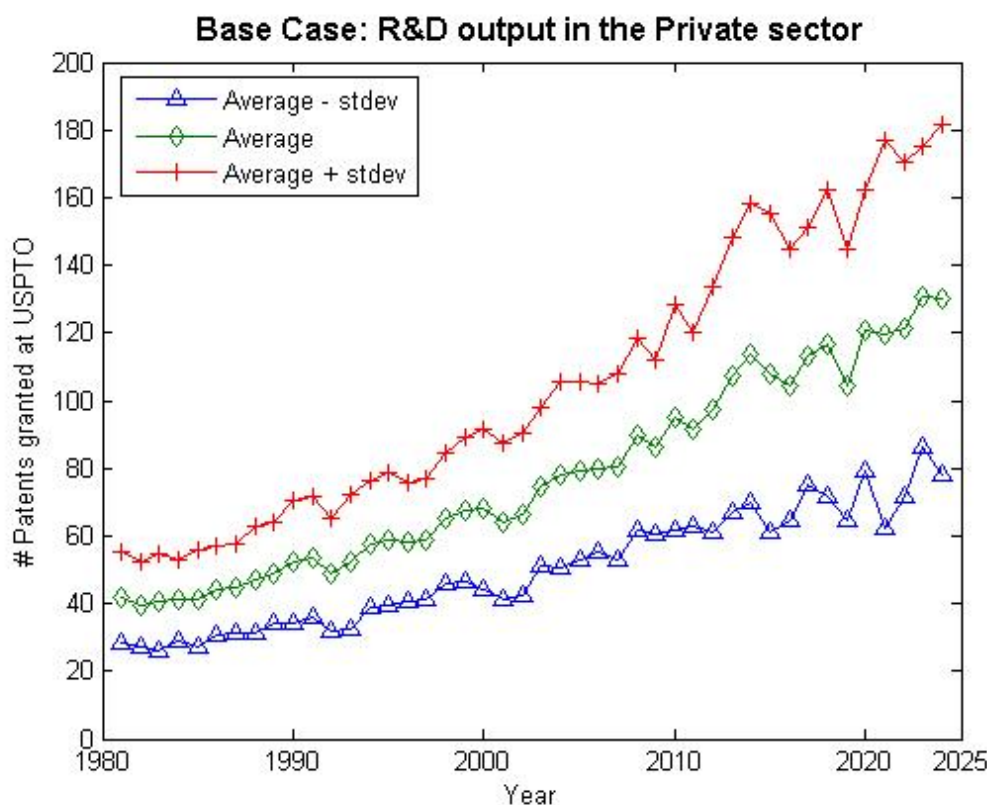


Figure 9-11 Absorption of Knowledge in the Private Sector under Base Case Conditions

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:

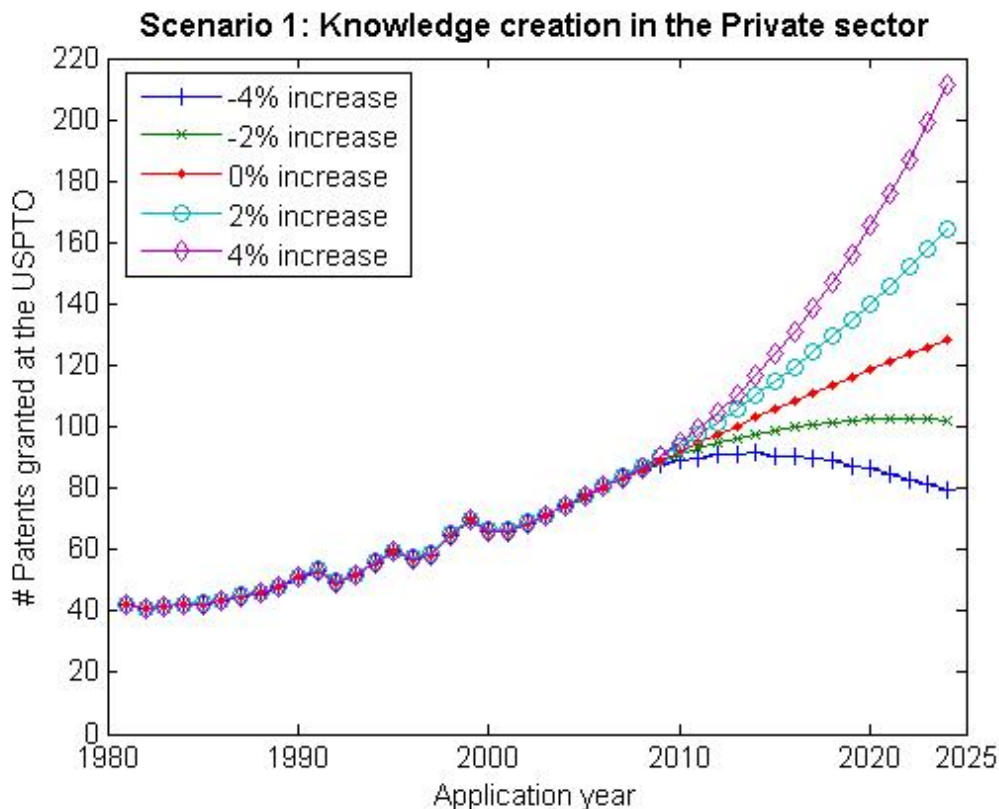


Figure 9-12 Scenario 1: Knowledge Creation in the Private sector

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.

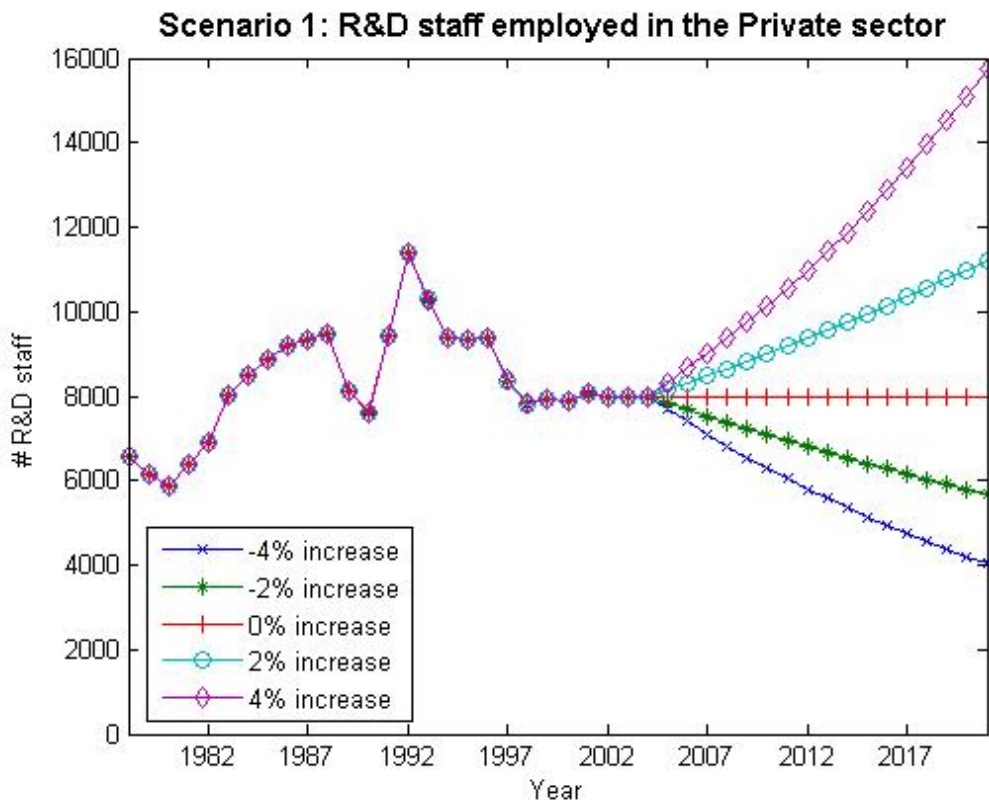


Figure 9-13 Scenario R&D Staff Employed in the Private Sector in South Africa

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.

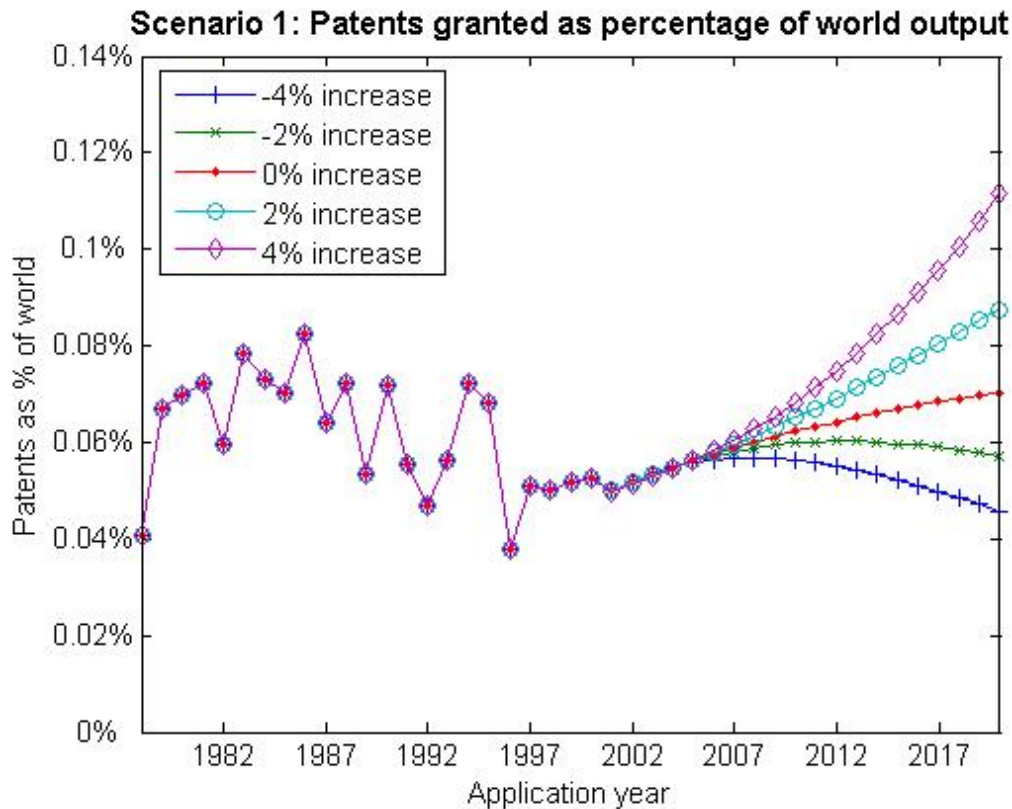


Figure 9-14: Scenario 1: Output as Percentage of World Output

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.

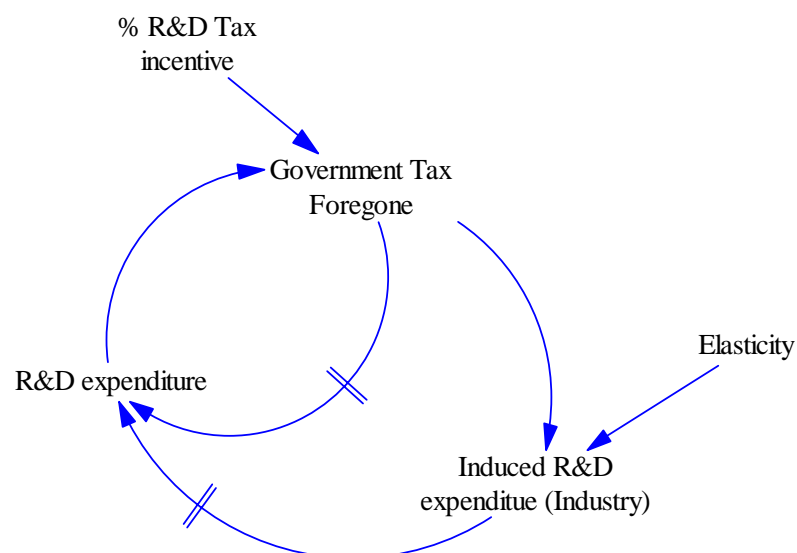


Figure 9-15: Causal loop of Fiscal Incentive Feedback Dynamics

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.

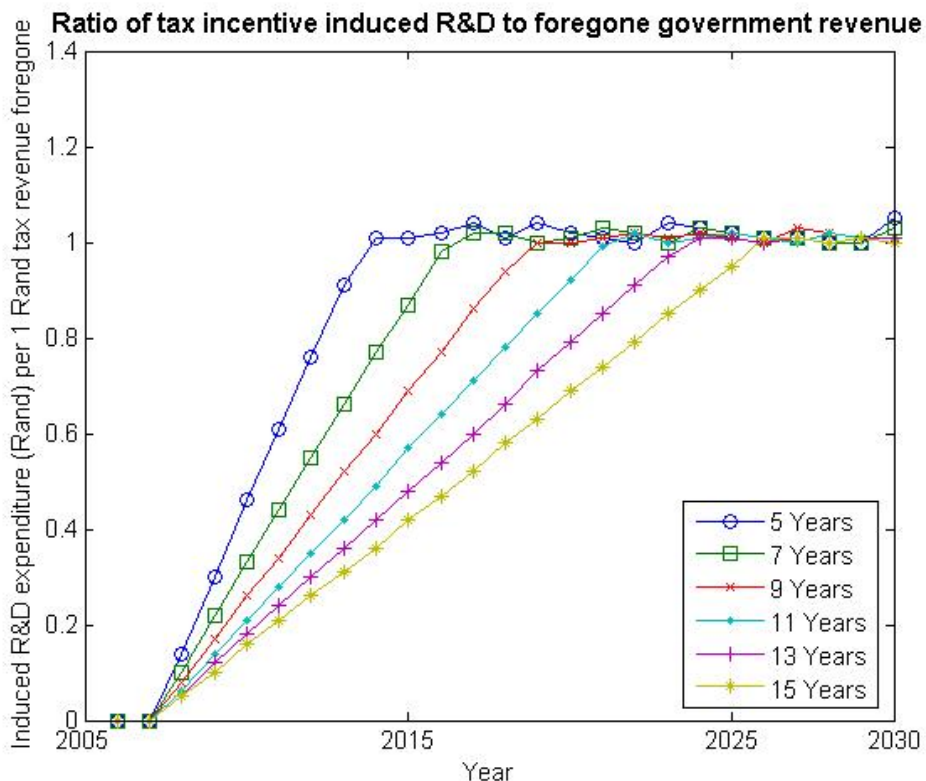


Figure 9-16: Scenario 2: Ratio of Tax Induced R&D to Foregone Government Revenue

Figure 9-16 illustrates that for a shorter 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.

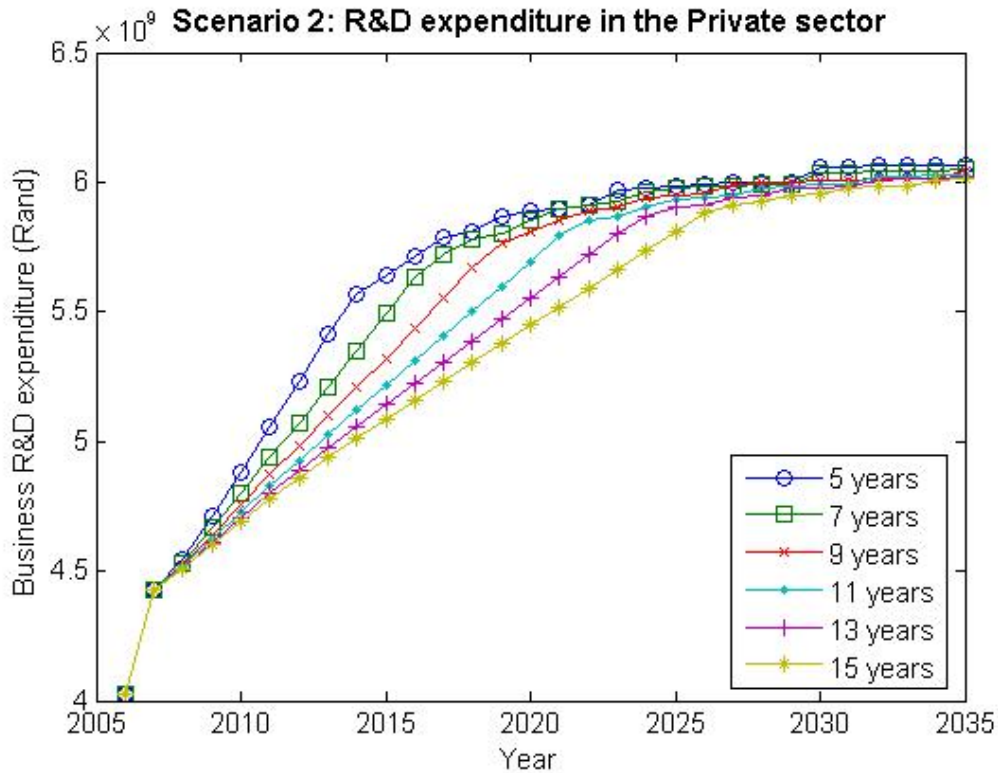


Figure 9-17: Scenario 2: R&D Expenditure in the Private Sector

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.

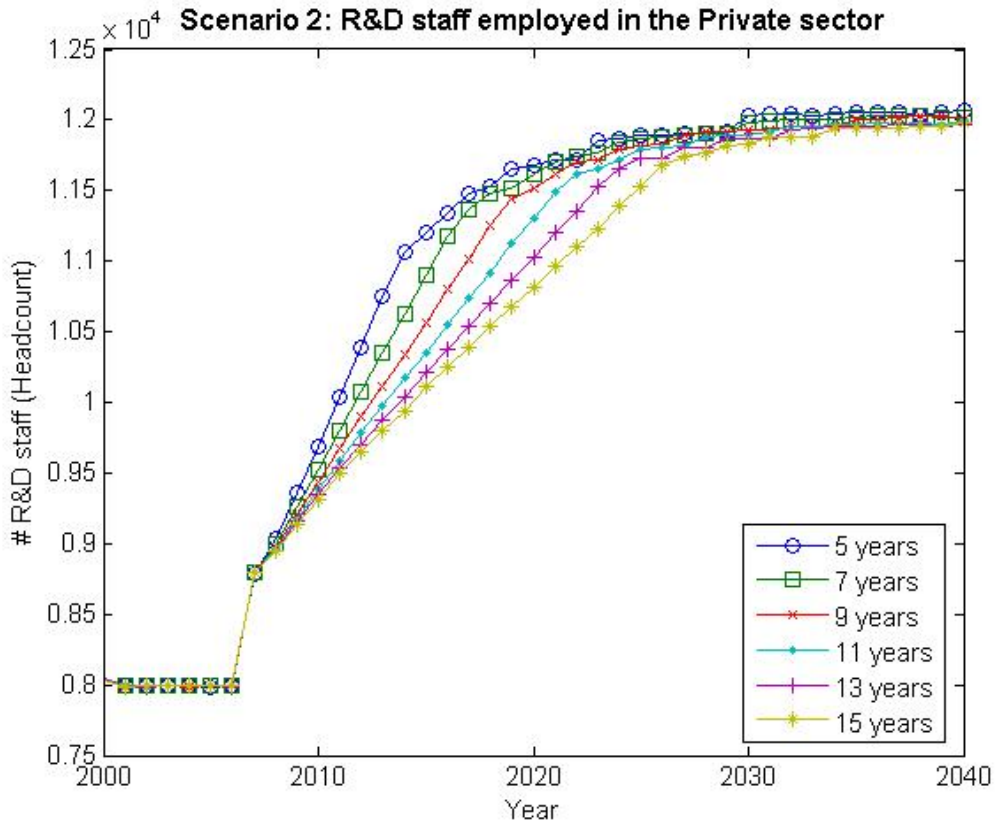


Figure 9-18: Scenario 2: R&D staff Employed in the Private sector

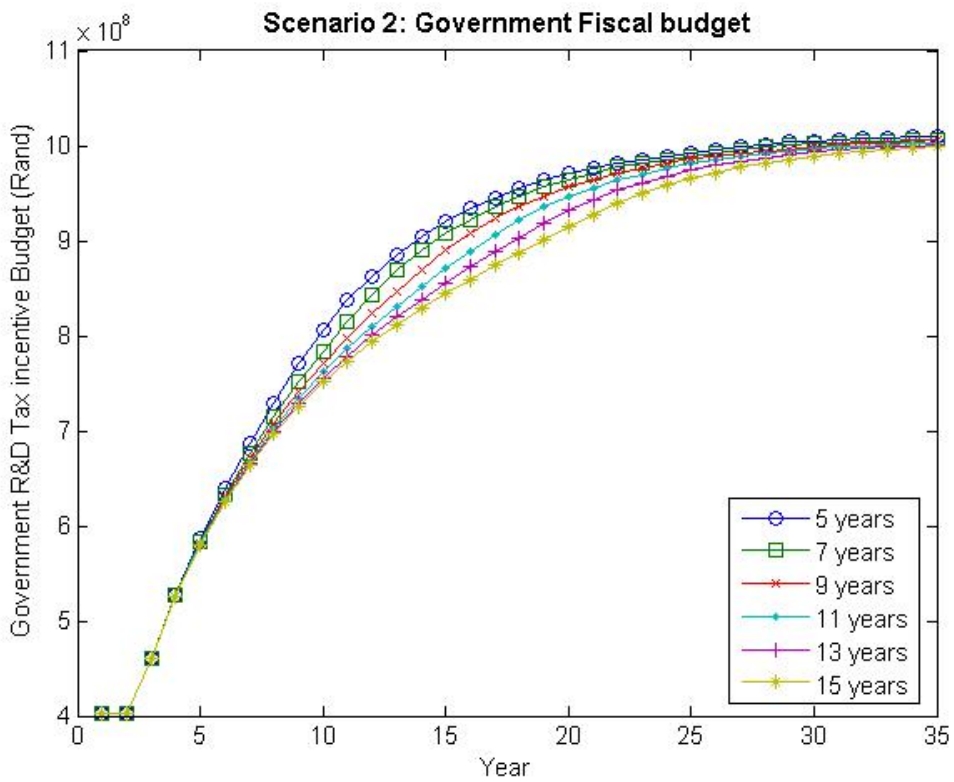


Figure 9-19: Scenario 2: Fiscal budget anchored at 20% of R&D expenditure

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.

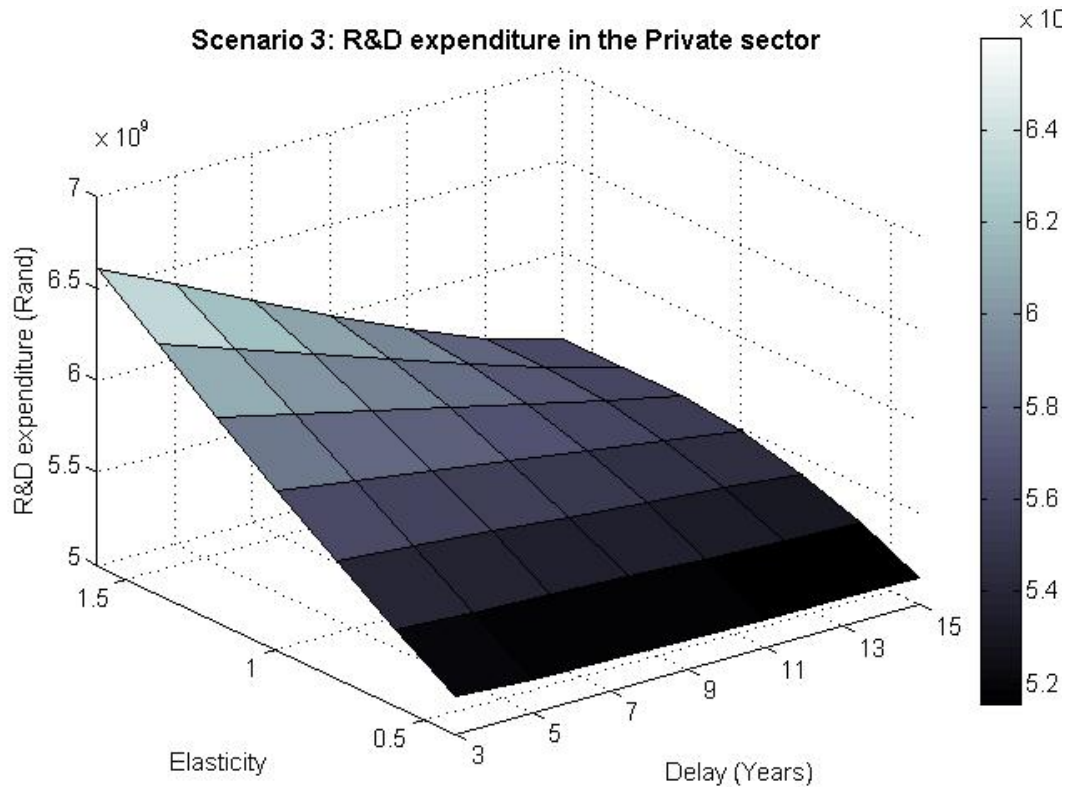


Figure 9-20 Scenario 3: Total R&D Expenditure in the Private Sector

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.

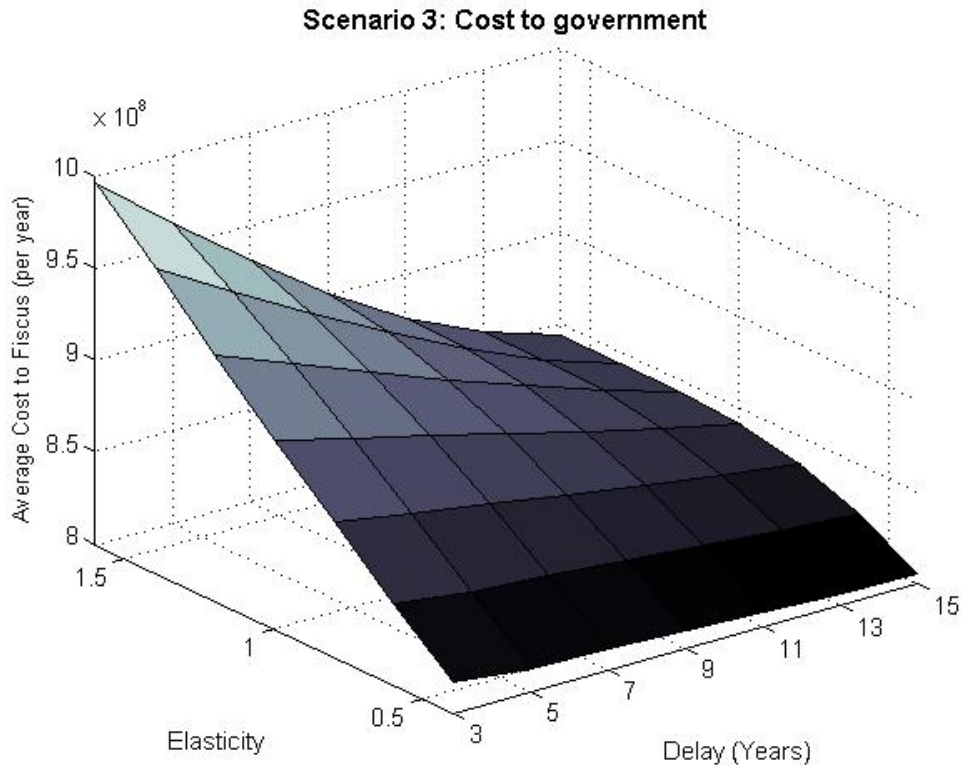


Figure 9-21: Government Contribution in Terms of Tax Breaks

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.

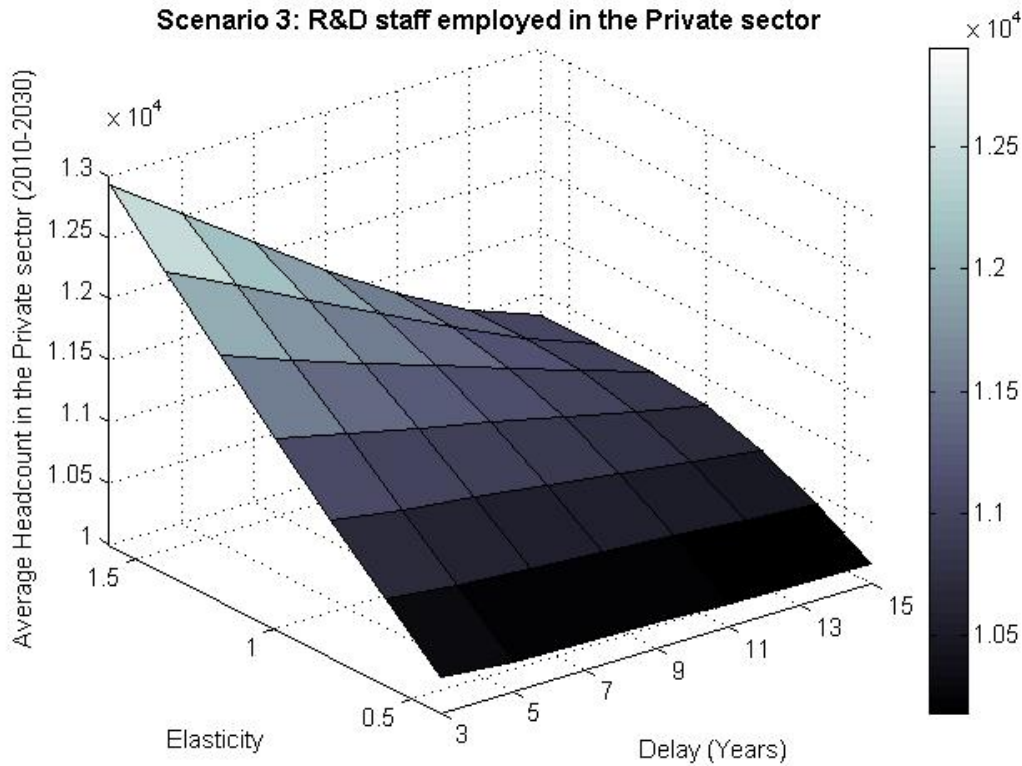


Figure 9-22: Scenario 3: R&D Staff Employed in the Private Sector

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.

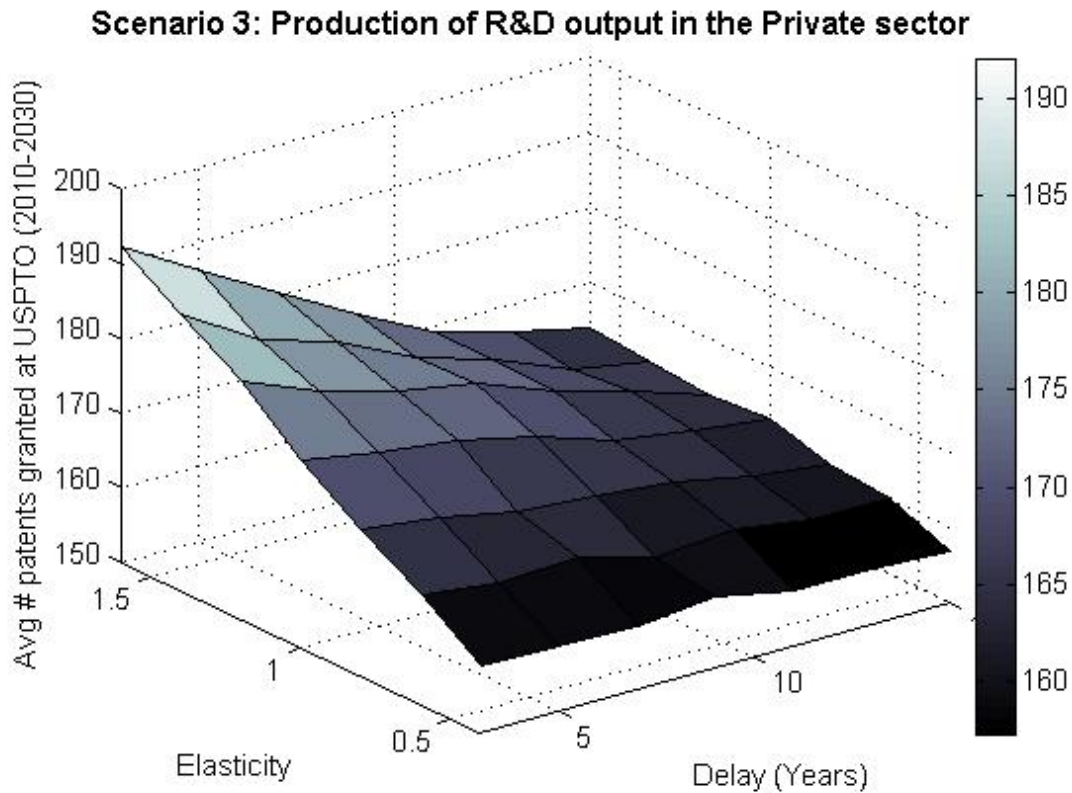


Figure 9-23: Scenario 3: Average Number of Patents Granted at the USPTO (2010 -2030)

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.

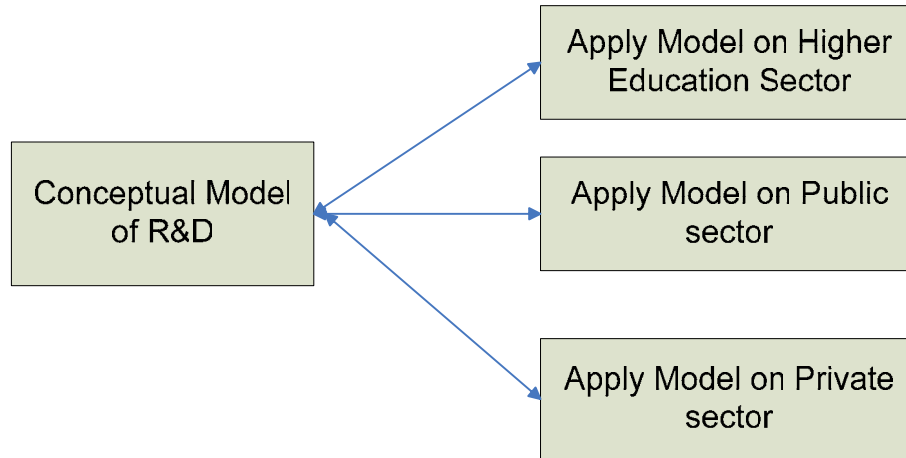


Figure 10-1: Application of Conceptual model to R&D sector

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 *scalable* 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 null 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 from 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.

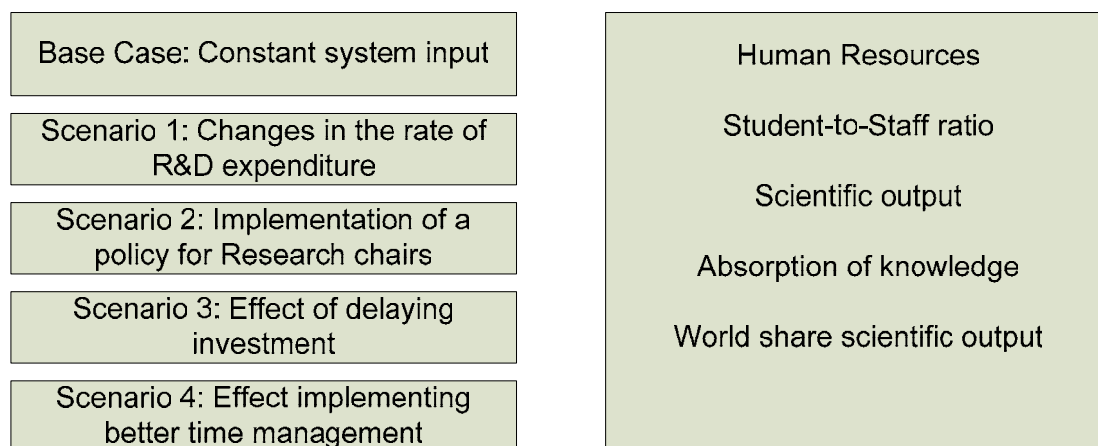


Figure 10-3: Scenario Tests on the Higher Education Sector Model

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.

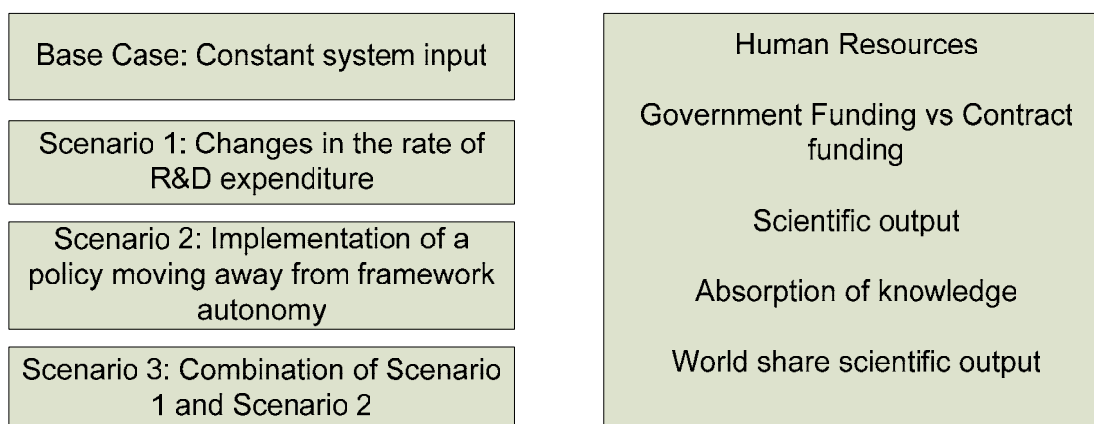


Figure 10-4: Scenario Tests on the Public Sector Model

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.

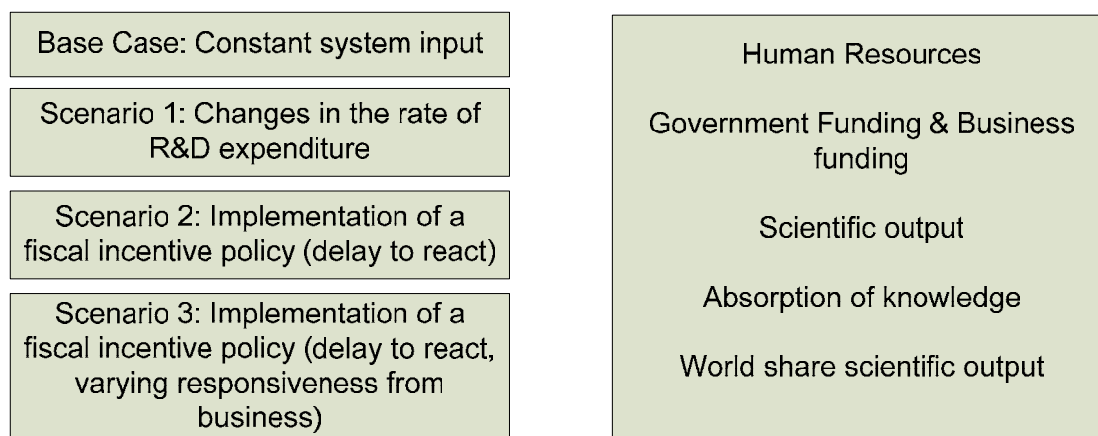


Figure 10-6: Scenario Tests on the Private Sector Model

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 to 2005
- 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 on 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 on 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 losing 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 on 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 on 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.