

# A CONCEPTUAL SYSTEMS DYNAMICS MODEL OF RESEARCH AND DEVELOPMENT ACTIVITIES IN SOUTH AFRICA

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## ABSTRACT

Research and Development (R&D) is one of the key sub-functions of a National System of Innovation (NSI). It is the primary point of entry for new scientific development and a key focus for industrial innovation. Recent trends show evidence of disinvestments and decay of South Africa's R&D capacity. The problem investigated in this study is the delayed effect and influence R&D investment has on the system's ability to produce R&D output. System Dynamics modelling is an excellent tool to assess a system's ability to adjust to change and the impact of new decisions that have to be made. The conceptual design of a System Dynamics model of R&D activities is presented. The theoretical underpinning and main assumptions made in deriving and developing the model are also discussed.

## OPSOMMING

Navorsing en Ontwikkeling (N&O) is een van die sleutelsub-funksies van 'n Nasionale Stelsel van Innovasie (NSI). Dit is die primêre toegangspunt vir nuwe wetenskaplike ontwikkeling en 'n sleutelfokus vir industriële innovasie. Onlangse neigings lewer bewyse van disinvestering en agteruitgang in Suid-Afrika se N&O-kapasiteit. Die probleem wat in hierdie studie ondersoek word, is die vertraagde effek en invloed wat N&O-investering op die stelsel se vermoë het om N&O-uitsette te lewer. Stelseldinamikamodellering is 'n uitstekende gereedskapstuk om 'n stelsel se vermoë om aan te pas by verandering te takseer en die impak van nuwe besluite wat geneem moet word te toets. Die konseptuele ontwerp van 'n Stelseldinamikamodel van N&O-aktiwiteite word voorgehou. Die teoretiese onderbou en die hoofaannames wat gemaak is in die afleiding en ontwikkeling van die model word ook bespreek.

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## **1. INTRODUCTION**

Chris Freeman [1] introduced the concept of a National System of Innovation (NSI) to describe and interpret the performance of Japan, the economically most successful country of the post World War II period. His definition of the NSI is: "the network of institutions of private and public sectors, whose activities and interactions initiate, import, modify, and diffuse new technologies".

The systems approach to innovation is based on the perception that innovations are brought about by the various components and the relations between them in the NSI. The innovation systems approach aims at identifying the main components and the interactions that play a part in performing the functions of the system.

De Wet [2] applied the NSI concept to the South African case and introduced the concept of a 'Technology Colony'. Technology Colonies are countries whose manufacturing industries are dependent on foreign technology because their NSIs are deficient or poorly developed. One of the authors (Buys [3]) used data obtained from the South African National Innovation Survey for the period 1998 – 2000 to characterize the South Africa's industrial base as being in Stage III of the backwards integration of a Technology Colony. He found that the most prevalent innovation activity in the South African NSI was the improvement of products and processes using foreign technology. Local Research and Development (R&D) played a very minor role in industrial innovation in South Africa.

These high-level descriptions now set the stage for a more dynamic analysis of South Africa's NSI. It is important to develop a dynamic description of the NSI to assist and guide decision makers to develop appropriate policies and to target the most important issues to elevate South Africa from its status as a Technology Colony.

## **2. R&D IN THE NATIONAL SYSTEM OF INNOVATION**

The analysis of the R&D function within a NSI framework does not suggest that it is the only activity performed in the system, it merely acknowledges the very important role R&D plays in this complex system. Freeman [1] states that although R&D is not the only source of technical change, R&D is one of the main points of entry for new scientific development and the main focus for the development of innovations in most branches of industry.

R&D is also introduced as a form of organizational learning [4]. Cohen and Levinthal [4] argue that R&D not only generates new information, but also enhances the ability to assimilate and exploit existing information. The long-term investment in developing R&D capacity is substantial and is not a trivial issue. The cost of learning is borne from the development of a stock of knowledge, which constitutes absorptive capacity.

Through the development of an R&D capacity, an absorptive capacity as well a capacity to create knowledge is built up. From this can be argued that the development of South Africa's R&D capacity is important for the further

development of its NSI.

### **3. PROBLEM STATEMENT**

Recent trends show evidence of disinvestments and decay of South Africa's R&D capacity:

- R&D expenditure in South Africa has slipped from 1.2% of GDP in 1987 to 0.76% in 2001. This is low when compared to the Organisation for Economic Co-operation and Development (OECD) average of 2.15% [5].
- Evidence exists that South Africa is slipping in its position as a knowledge creator. South Africa has dropped from creating 0.8% of the world's scientific output in 1990 to 0,5% in 2002 [5].
- More alarming is the fact that South Africa has an ageing R&D workforce. A lack of rejuvenation in the human resource base exists where researchers in the age cohort 30 to 49 dropped from 77% in 1990 to 45% in 1998 [6].

Rightfully so these trends are a cause of considerable concern for policy makers in South Africa. Questions arise regarding the detrimental effects these trends could have on the ability of South Africa to generate R&D output. If these problems are not addressed and the system is allowed to decay, the costs of rebuilding the system will increase.

None of the current descriptions of the South African NSI adequately explains causal relationships between elements in the South African R&D system and resulting R&D outputs. The problem investigated in this research project is the delayed effect and influence R&D investment has on the system's ability to produce R&D output. From this follows the following research question regarding the South African NSI's dynamic behaviour:

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

### **4. METHODOLOGY**

Within a complex system events and development take place over time, and is path dependent: small events are reinforced through positive feedback loops and can become very important. History plays an important role in the level of development of a system [7]. The methodology chosen for this research project therefore must be able to incorporate the reservoir effects and feedback loops prevalent in an R&D system.

Forrester [8] states that differential equations seem to be better suitable to describe the behaviour of economic systems than algebraic equations often used in economics. Delays, momentum, elasticities, reservoirs and acceleration are the fundamental quantities differential equations have been developed to describe. By employing differential equations, Forrester developed Systems Dynamics (SD) as an analytical tool to improve decision-making and policy formation for complex

systems. This methodology can be used to include relevant cause-effect relationships, delays and feedback loops in complex systems through the development of stocks and flow diagrams.

System Dynamics models are simplifications of reality based on the analyst's understanding of the system and assumptions made regarding expected behaviour. System Dynamics modelling in management sciences proves to be a very useful tool. The approach is an excellent tool to assess a system's ability to adjust to change and to test new decisions that have to be made. System Dynamics models are mainly used for:

- Policy testing [8]
- What-if scenarios [9]
- Policy optimisation [10]

It has to be acknowledged that System Dynamics models of social systems are not nearly as accurate as those for mechanical systems. Two of the main reasons for this phenomenon are that social systems are far more complex than technical systems and that it is very difficult to find reliable indicators of variables in social systems. However, the methodology has successfully been used to develop models of social systems. Jay Forrester discusses the applications of Systems Dynamics to urban, corporate and global sustainability problems in his paper *Counterintuitive behaviour of social systems* [11].

Given the technical backgrounds of the initial practitioners of Systems Dynamics they were inclined to apply the methodology to areas they knew best, namely R&D management problems. In terms of the modelling of R&D systems, System Dynamics has been used to model numerous systems at a single project level. Repenning lists influential models in scholarly literature on single models for R&D [12].

SD has also been used to develop models of R&D systems at an aggregate level. Examples of such Systems Dynamic models include the following:

- SD model of a regional R&D system in the JiLin Province in China [13],
- Long term investment in military R&D in Taiwan [14] and
- A Leverage strategy to R&D investment in South Korea (Park et al) [15].

Zhang and Qu [13] specifically comment on the usefulness of the System Dynamics approach within a system of innovation framework. The prevalence of feedback chains in innovation systems cause structural and behavioural complexities and give rise to non-linear interrelationships between elements in innovation systems.

Developing a Systems Dynamics model is an iterative process [16][17]. The modelling process is a continual process of formulating propositions, testing, and the evaluation of formal and mental models. Various researchers have organized the modelling activities in different stages each using a different set of arguments [18]. This research project follows the steps as described by Sterman [17] in his book

Business Dynamics.

## **5. DEVELOPMENT OF THE DYNAMIC PROPOSITIONS**

The successful development of a dynamic description of the R&D function is dependent on the availability of time-series data. The Frascati manual serves as a document for standardising the collection of national R&D information. South Africa is committed to follow this approach and has been conducting Frascati surveys since the early 1960's. This research project makes use of the sectoral breakdown as prescribed in the Frascati manual for the collection of R&D data [19]. From the five sectors identified only the higher education sector, public sector and business sector will formally be modelled. The non-profit sector makes a very small contribution to national R&D output in South Africa and will therefore not be included in the analysis. The abroad sector's influence is included and implied in the models of the three sectors.

Many aspects and theoretical principles of the performance of R&D are similar across different R&D sectors in a country. The strategy followed in developing the simulation model is the development of a single sectoral model for R&D. In order to simplify the task of developing a model for the South African R&D system, the basic building block of the development of a sectoral R&D system is therefore derived first, after which it will be applied to the other sectors.

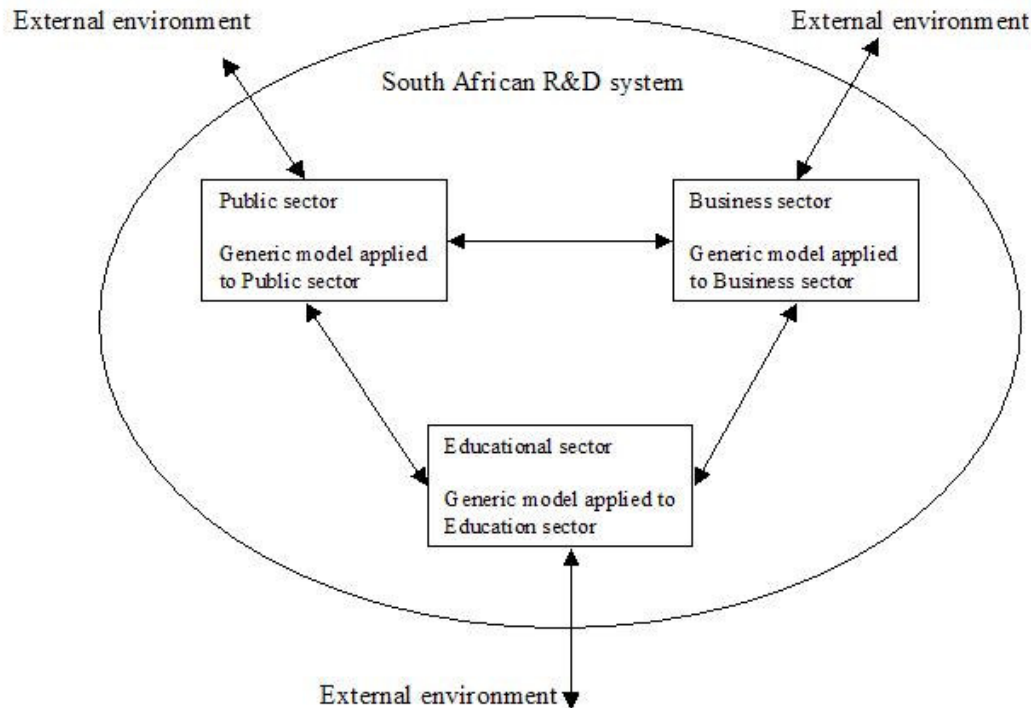
This paper deals with the development of this generic model structure. Figure 1 explains the approach in greater detail.

Now that a high-level view of the model structure has been explained, the derivation of dynamic propositions can follow. The following section deals with the derivation of a causal loop diagram of a sectoral R&D system.

As already mentioned, history plays an important role in the level of development of a system [7]. The model developed in this section acknowledges the important role that the accumulation of knowledge and skills play in the development of an R&D system.

Many authors [20][21][22][23] agree on the presence of human resources as an important input to the performance of R&D. Human resources are engaged in R&D activities over a period of time. By engaging in these R&D activities, human resources accumulate tacit knowledge, know-how and skills, which develop through experience. Tacit knowledge plays a very important role in the development of new knowledge. Nelson and Winter [19] argue that to be able to deploy R&D activities, much tacit knowledge is involved. The sharing of tacit knowledge requires intensive interaction and in many cases the physical presence of actors involved in the sharing process since articulation of this kind of knowledge in for instance coded knowledge is difficult or even impossible. Non-codifiable knowledge or tacit knowledge encompasses the following:

- “learning by doing”[24],
- “learning by using” [25] and
- “learning by interacting” [22].



**Figure 1: High-level view of the model structure**

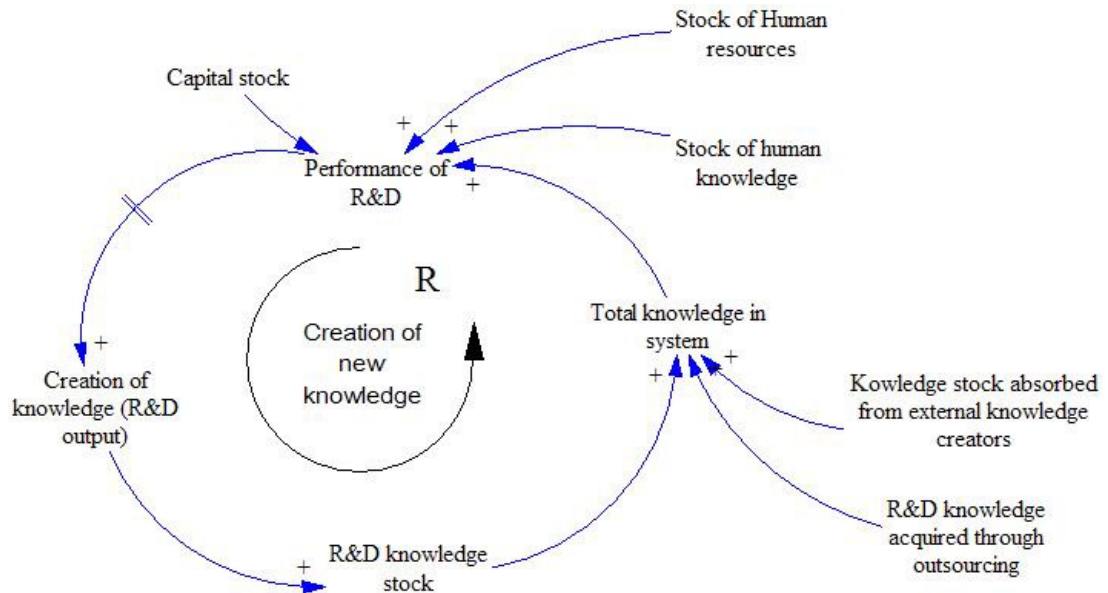
Lundvall [22] and Johnson’s [23] theory of interactive learning makes provision for the deterioration of knowledge as it falls out of use or is replaced by new knowledge. As R&D is performed in the system, the knowledge created can be expected to remain current and relevant only for a period of time after which it will become obsolete.

From this section therefore can be concluded that human resources play an important part in the development of new knowledge. Through the development of new knowledge, human resources also gain insight and skills (referred to as tacit knowledge). Human resources take part in the processes of R&D. The following sections deal with the dynamic processes of human resources engaged in learning and the development of new knowledge.

### **5.1 The generation of new knowledge**

From the definition of R&D as stated in the Frascati manual: R&D comprises the creation of knowledge, including knowledge of man, culture and society through the use of the stock of knowledge to devise new solutions [26]. This definition highlights the central role knowledge plays in the generation of new knowledge. Many authors [4][22][20] support this view in their work. This is incorporated in the causal loop depicted in Figure 2.

In Figure 2, the dynamic propositions derived aim to capture the process of the performance of R&D. The diagram captures a reinforcing loop. Human resources in an R&D system draw on capital stock (buildings, land and equipment) resources [7][26][21], knowledge stocks within the system as well as their own expertise and experience to perform R&D activities.



**Figure 2: Creation of new knowledge loop**

Human resources also gain experience through the performance of R&D activities resulting in a higher level of experience and expertise [24][22][25]. Through the performance of R&D activities new knowledge is created resulting in more knowledge being added to the “R&D knowledge stock”.

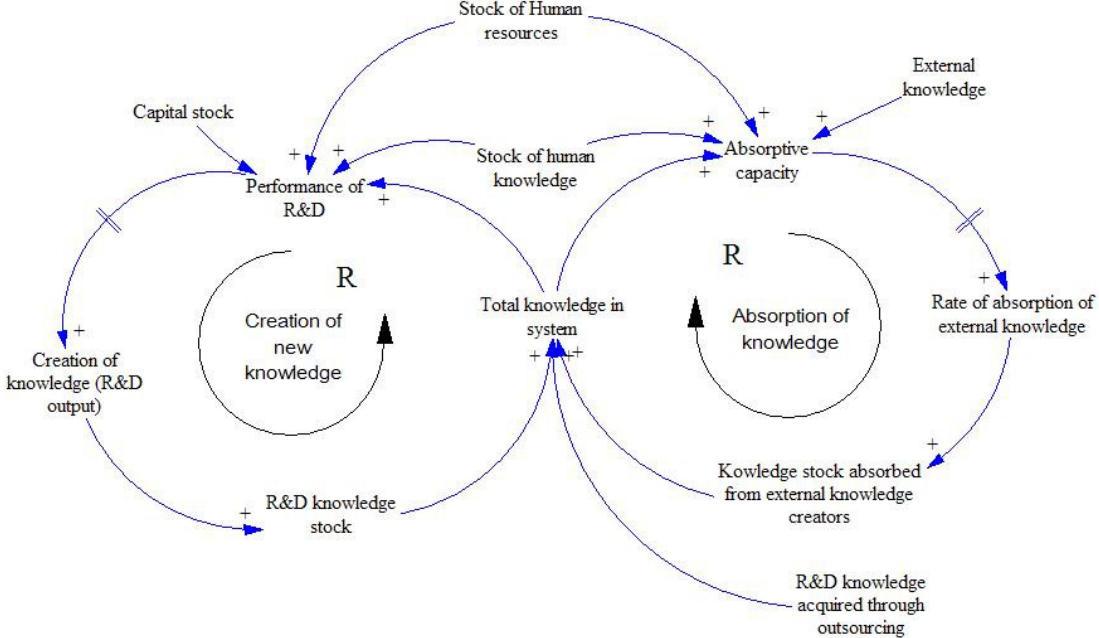
Apart from the R&D knowledge stock and tacit knowledge of researchers, two additional knowledge stocks also drawn on in the performance of R&D activities can be identified. These stocks of knowledge are knowledge that has been acquired from external sources and through outsourced R&D [4]. The following section describes the accumulation of these knowledge stocks in greater detail.

## 5.2 The absorption and acquisition of external knowledge

Absorptive capacity refers to the firm’s repertoire of innovation-directed problem solving routines consisting of knowledge of task execution. Knowledge for innovation is often “lent” from the environment instead of being created within an organisation itself [27]. To this aim knowledge for innovation must be absorbed through interaction and co-operation through feedback loops with the network of relationships with the outside world.

From this can be concluded that the performance of R&D is also dependent on the

acquisition and absorption of knowledge from external sources. This also implies that the organisation must have the ability to identify, absorb and apply new knowledge for its own means – commonly referred to as the “absorptive capacity” [4]. The dynamic propositions displayed in figure 3, represent a reinforcing loop for the building of system knowledge through the absorption and acquisition of external knowledge.



**Figure 3: Accumulation of knowledge**

The ability to absorb information, the amount of knowledge actually transferred into the organisation is also dependent on the quantity, quality and the kind of knowledge available in the external environment. In order to include this aspect, the dynamic propositions include the influence of the stock of knowledge created in the external environment on the absorptive capacity on the system.

The diagram distinguishes between knowledge absorbed from the external environment and knowledge acquired through the outsourcing of R&D. This is based on the assumption that if sectors outsource R&D to another party, they will then receive the outcomes of the R&D in return for funding of the research resulting in knowledge being transferred to the sector.

Since the successful performance of R&D depends on the successful integration of external and internal knowledge stocks, the following section deals with the combination of the feedback loops derived.

From the causal loop diagram, the relationships between variables and the feedback structure of the system can be communicated. Causal loop diagrams however do not provide a way of communicating the model’s physical structure. Causal loops also fail to capture the accumulation of goods as a result of flows in the system. The causal loop diagram developed up to this point therefore will now be expanded further into a stock and flow diagram.

### 5.3 Formulation of a Stock and flow diagram

The formulation of the stock and flow diagram is done through the formulation of the rate (flow) equations. Before the model is discussed in more detail, the notation of the formulation of the rate equations is first explained. This involves the formulation of mathematical equations for estimating the influence changes in stocks in the system might have on one another. To estimate the effect a change in a stock ( $X_1$ ) could have on a variable (Y) the following formulation is used:

$$\text{Change in Y as a result of } X_1 = f\left(\frac{X_i}{X_i^*}\right)$$

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

*Reference levels throughout the model formulation are chosen to be the values for the initial level of stocks and rates in the model (i.e. the level of the stocks or rates at time = 0).*

Throughout the model, the change in variable Y because of  $X_1$  is modelled to take a power function form of the normalised inputs:

$$\text{Change in Y as a result of } X_1 = \left(\frac{X_i}{X_i^*}\right)^{a_i}$$

An advantage of using the power law model in a multiplicative formulation is that it can be rewritten in a log linear format. Parameters can then be estimated through linear regression.

The first aspect of the stock and flow diagram that is looked into is the human resources stock and their associated tacit knowledge. The following section explains this sub-section of the stock and flow diagram in more detail.

### 5.4 Human Resources

As described in the derivation of the causal loop diagram, an R&D performing sector has its *Human Resources Stock* contributing to the creation and development of new technologies. The stock of human resources ( $S_{HR}$ ) in the system is a function of the rate at which researchers are employed into the system ( $R_{Employ}$ ) and the rate at which researchers leave the system ( $R_{Leave}$ ).

$$S_{HR} = \text{Integral} (R_{Employ} - R_{Leave})$$

It can be argued that the average researcher with 10 years experience should be more efficient and effective in performing R&D (embodies a higher concentration of tacit knowledge and has more cooperation and relationships with other researchers) than the average graduate who has just completed his/her studies. As researchers retire or leave the R&D workforce, the system loses a valuable resource with years of experience. Following this reasoning an assumption is made that as the average level of experience in the system rises, the tacit knowledge, know-how, general capability and cooperation of the researchers in the system will rise as well.

The following stock and flow structure is developed to attempt to capture these flows and the accumulation of human resources and experience.

In associating the accumulation of skills in the system with the human resource stock in the system, the formulation of the model makes use of a co-flow structure. The stock of human knowledge is quantified in terms of years of experience. This is based on the assumption made earlier that researchers with more experience have more tacit knowledge and skills.

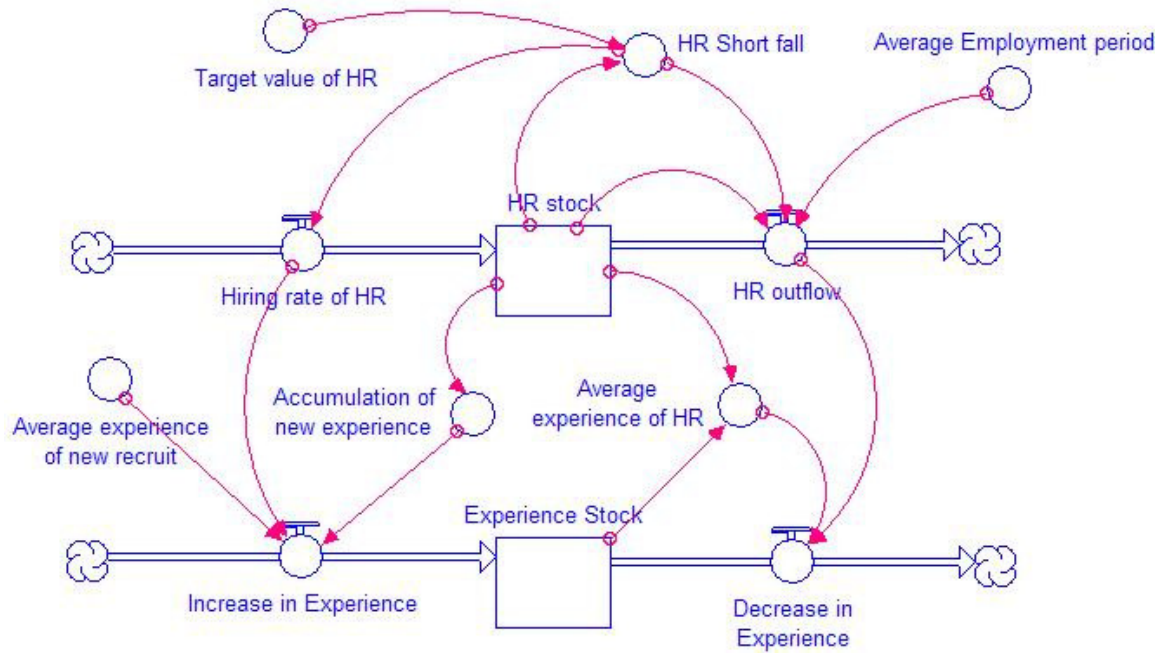
The Stock of skills in the system ( $S_{skills}$ ) accumulates through the rate at which human resources enter the system ( $R_{Employ}$ ) and with an average level of experience they already possess per researcher ( $A_{New-experience}$ ). Through the performance of research tasks researchers also gain experience and tacit knowledge. This results in a build-up of the stock of human knowledge in the system - modelled in terms of the number of researchers employed in the system ( $S_{HR}$ ) – embodying the total experience gained through the year. As researchers leave the system, experience and tacit knowledge will also be lost to the R&D performing sector. The stock of skills is also diminished at a rate which the average experience ( $A_{leaving-experience}$ ) embodies in researchers leaving the system. The stock of human knowledge therefore is modelled through the following rate equations:

$$S_{skills} = \text{Integral} ( R_{Employ} * A_{New-experience} + S_{HR} - R_{Leave} * A_{leaving-experience} )$$

$$A_{leaving-experience} = S_{skills} / S_{HR}$$

For the system to continue producing research output, it is important to have a human resources stock that is continually replenished with new graduates. The current experience stock (measured in total years experience in R&D by all human resources in the system) is therefore identified as an important input to the performance of R&D in the system.

This section has described the human resources subsystem of the model. The following section focuses on the role of knowledge stocks and human resources on the performance of the system



**Figure 4: The Stock and flow diagram of Human resources and Experience.**

### 5.5 Effect of Knowledge and HR on system performance

The model makes use of a common performance variable to estimate the performance of the system. The first factor contributing to the performance of the R&D system ( $A_{Performance}$ ) is the availability of human resources. The change in the system performance as a result of changes in the human resources stock ( $HR$ ) therefore can be expressed as follows:

$$\text{Change in } A_{Performance} \text{ as a result of } HR = \left( \frac{HR}{HR_1} \right)^{a_5}$$

The second factor influencing the system's performance is the knowledge in the system. Considered in the formulation are the following knowledge stocks that have been identified previously:

- R&D knowledge stock ( $S_{RD}$ ): Stock of R&D output generated in the system
- Acquired knowledge stock ( $S_{Acquired}$ ): R&D output acquired by the R&D performing sector by funding R&D or paying for the transfer of knowledge to the sector.
- Absorbed knowledge stock ( $S_{Absorbed}$ ): Knowledge external to the R&D performing sector that has been absorbed through the course of performance of R&D.

- Human resources knowledge stock ( $S_{HR}$ ): Tacit knowledge and research skills inherent to the human resources working in the system<sup>2</sup>

The multiplicative formulation for the influence knowledge stock might have on the system performance ( $A_{Performance}$ ) is then formulated to take the following form:

Change in  $A_{Performance}$  because of Knowledge =

$$\left(\frac{S_{HR}}{S_{HR}^*}\right)^{a_1} * \left(\frac{S_{Acquired}}{S_{Acquired}^*}\right)^{a_2} * \left(\frac{S_{Absorbed}}{S_{Absorbed}^*}\right)^{a_3} * \left(\frac{S_{RD}}{S_{RD}^*}\right)^{a_4}$$

## 5.6 Change in System performance

In order to estimate the changes in system performance because of the knowledge in the system as well as the human resources the following formulation is chosen:

Change in  $A_{Performance} = (\text{Change in system performance because of HR}) * (\text{Change in system performance because of Knowledge})$

Which leads to the following formulation:

$$\text{Change in } A_{Performance} = \left(\frac{S_{HR}}{S_{HR}^*}\right)^{a_1} * \left(\frac{S_{Acquired}}{S_{Acquired}^*}\right)^{a_2} * \left(\frac{S_{Absorbed}}{S_{Absorbed}^*}\right)^{a_3} * \left(\frac{S_{RD}}{S_{RD}^*}\right)^{a_4} * \left(\frac{S_{HR}}{S_{HR}^*}\right)^{a_5}$$

Now that an expression of the fractional change in System performance has been formulated, the feedback loops feeding from and into the system performance parameter can be characterised. From the causal loop diagram as well as the outline of the stock and flow diagram it can be seen that the model consists of two reinforcing feedback loops.

Absorption of external knowledge  
Creation of knowledge

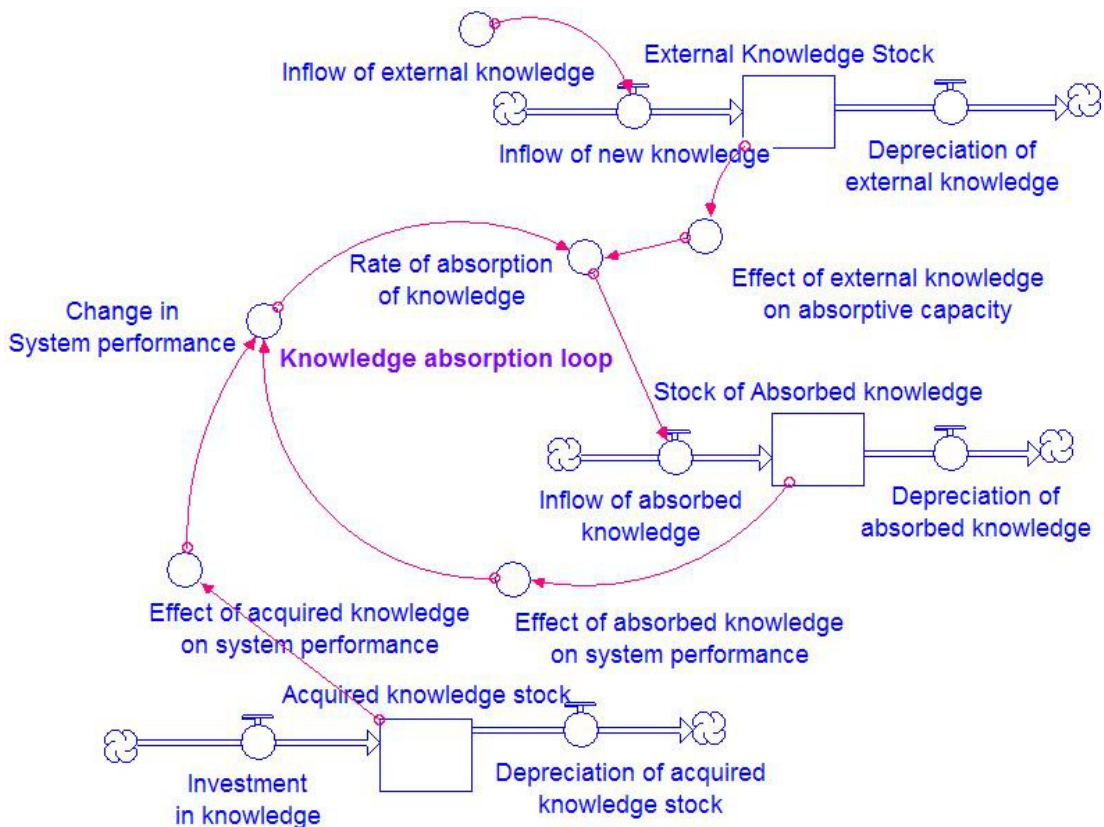
## 5.7 Loop 1: Absorption of external knowledge

Figure 5 depicts the stock and flow diagram developed for the knowledge Absorption and acquisition sub-system. In this stock and flow diagram, the rate of creation of knowledge in the external environment ( $R_{External}$ ) is defined to be exogenous to the system. As knowledge is created in the external environment it forms part of the total stock of knowledge in the external environment ( $S_{External}$ ).

<sup>2</sup> Sterman [17] makes use of the power law formulation to model productivity of workers as a function of the average experience of workers. Sterman makes reference to Zangwill and Kantor [28] for the derivation of various forms of learning curves.

$$S_{External} = \text{Integral} (R_{External} - \text{Depreciation rate of external knowledge})$$

As R&D is performed in the system, knowledge is absorbed from the external environment. The rate at which the system absorbs the knowledge is defined as the Absorptive capacity. The model defines it as the rate the system is able to absorb knowledge from the external environment. The quantity, quality, applicability and context of the knowledge ( $S_{External}$ ) in the external environment also impact on the ability of the system to absorb the knowledge ( $R_{Absorption}$ ). The knowledge absorption rate is modelled through the following mathematical equation:



**Figure 5: The absorption of external knowledge**

$$\text{Knowledge absorption rate } (R_{Absorption}) = R_{Absorption}^* * (\text{Fractional Change in } A_{Performance}) * (\text{Change in Absorptive capacity because of } S_{External})$$

With

$$\text{Change in absorptive capacity because of } S_{External} = \left( \frac{S_{External}}{S_{External}^*} \right)^{\alpha_7}$$

The rate at which knowledge is absorbed feeds into the stock of knowledge that has been absorbed from the external environment ( $S_{Absorbed}$ ). The accumulation of the

absorbed knowledge stock is modelled to take the following form:

$$S_{Absorbed} = \text{Integral} (R_{Absorption} - \text{Depreciation rate of absorbed knowledge})$$

The absorbed knowledge stock ( $S_{Absorbed}$ ) feeds back into the system equation for the change in system performance. The second feedback loop whose output affects the system performance is the performance of R&D. The following section describes this loop in more detail.

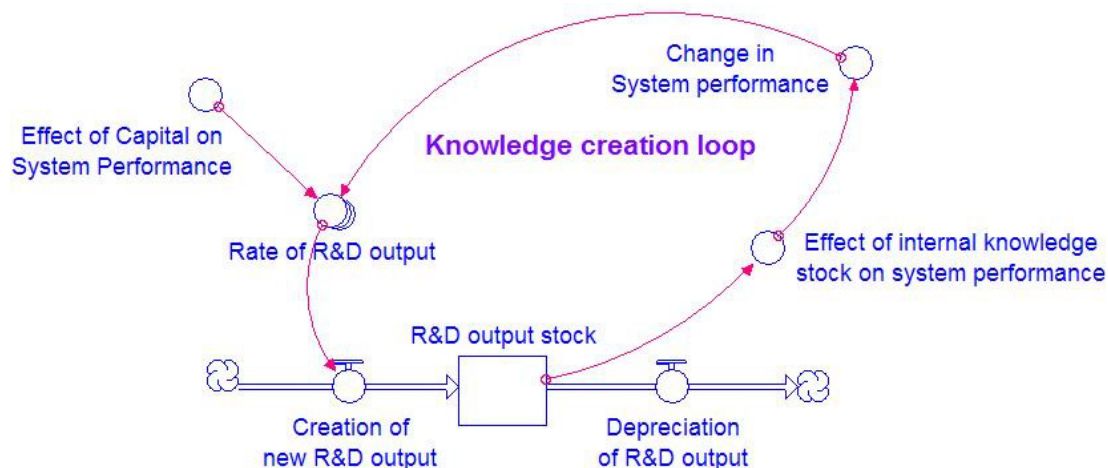
### 5.8 Loop 2: The Performance of R&D

The second reinforcing loop deals with the internal creation of knowledge in the system. The following stock and flow diagram displays the “Internal generation of Knowledge” loop.

In the development of the causal loop diagram, it was derived from theory that the “rate of the creation of new knowledge”  $R_{R\&D}$  dependent on the stock of human resources and different types of knowledge contained in the system (of which their influence is integrated in the System Performance Parameter ( $A_{Performance}$ )). Another factor influencing the performance of R&D activities is the Capital Stock ( $S_{Capital}$ ) in the system. The inclusion of the Capital Stock into the model attempts to include the role played by equipment and facilities available to R&D workers. The “Performance of R&D” variable can therefore be expressed by the following mathematical formula:

R&D knowledge stock = **Integral** (rate of creation of R&D output - depreciation of R&D knowledge)

$$S_{R\&D} = \text{Integral} (R_{R\&D} - \text{depreciation of R\&D knowledge})$$



**Figure 6: Stock and flow diagram for the Performance of R&D**

Performance of R&D (rate) = (Reference rate of R&D in 2001)\* (Change in R&D because of Capital)\*(Change in  $S_{Performance}$ )

$$R_{R\&D} = R_{R\&D}^* \left( \frac{S_{Capital}}{S_{Capital}^*} \right)^{\alpha_s} * A_{Performance}$$

Closing the reinforcing feedback loop, the R&D knowledge stock feeds back into the system performance computation equation.

## 6. CONCLUSION

In this paper, the causal loop structure of an R&D performing sector was derived. The theoretical underpinning and the main assumptions made in deriving and developing the model were presented. The basic building blocks and dynamic propositions of the process of the generation of new knowledge have been derived and stock and flow diagrams were developed. The stock and flow diagrams derived represent a generic model of R&D at the sectoral level. This is an important step towards the development of a Systems Dynamics model of R&D in South Africa. This conceptual model can now be modified and applied to the three R&D performing sectors of South Africa (Higher Education Sector, Public Sector and the Business Sector).

Although this paper only deals with the derivation of the conceptual model, the following table summarises the quantification of the defined stocks in the conceptual model:

<b>Variable</b>	<b>Higher Education system</b>	<b>Public sector</b>	<b>Private sector</b>
$HR$	Full Time Equivalent (FTE) Researchers employed in sector	Full Time Equivalent (FTE) Researchers employed in sector	Full Time Equivalent (FTE) Researchers employed in sector
$S_{HR}$	Summation of FTE researchers employed in the system over consecutive years	Summation of FTE researchers employed in the system over consecutive years	Summation of FTE researchers employed in the system over consecutive years
$S_{RD}$	Summation of scientific papers originating from sector	1. Summation of scientific papers originating from sector and 2. Summation of scientific patents originating from sector	Summation of patents originating from sector
$S_{Acquired}$	Royalty payments made by sector	Royalty payments made by sector	Royalty payments made by sector
$S_{Absorbed}$	Summation of references made in scientific papers originating from sector	1. Summation of references made in scientific papers originating from sector and 2. Summation of references made in scientific patents originating from sector	Summation of references made in scientific patents originating from sector
$S_{Capital}$	Accumulated value of investment in Capital in the sector	Accumulated value of investment in Capital in the sector	Accumulated value of investment in Capital in the sector

**Table 1: Quantification of variables in model**

The Systems Dynamics model will be used to assess the R&D sector's ability to adjust to change and the impact of new decisions that have to be made.

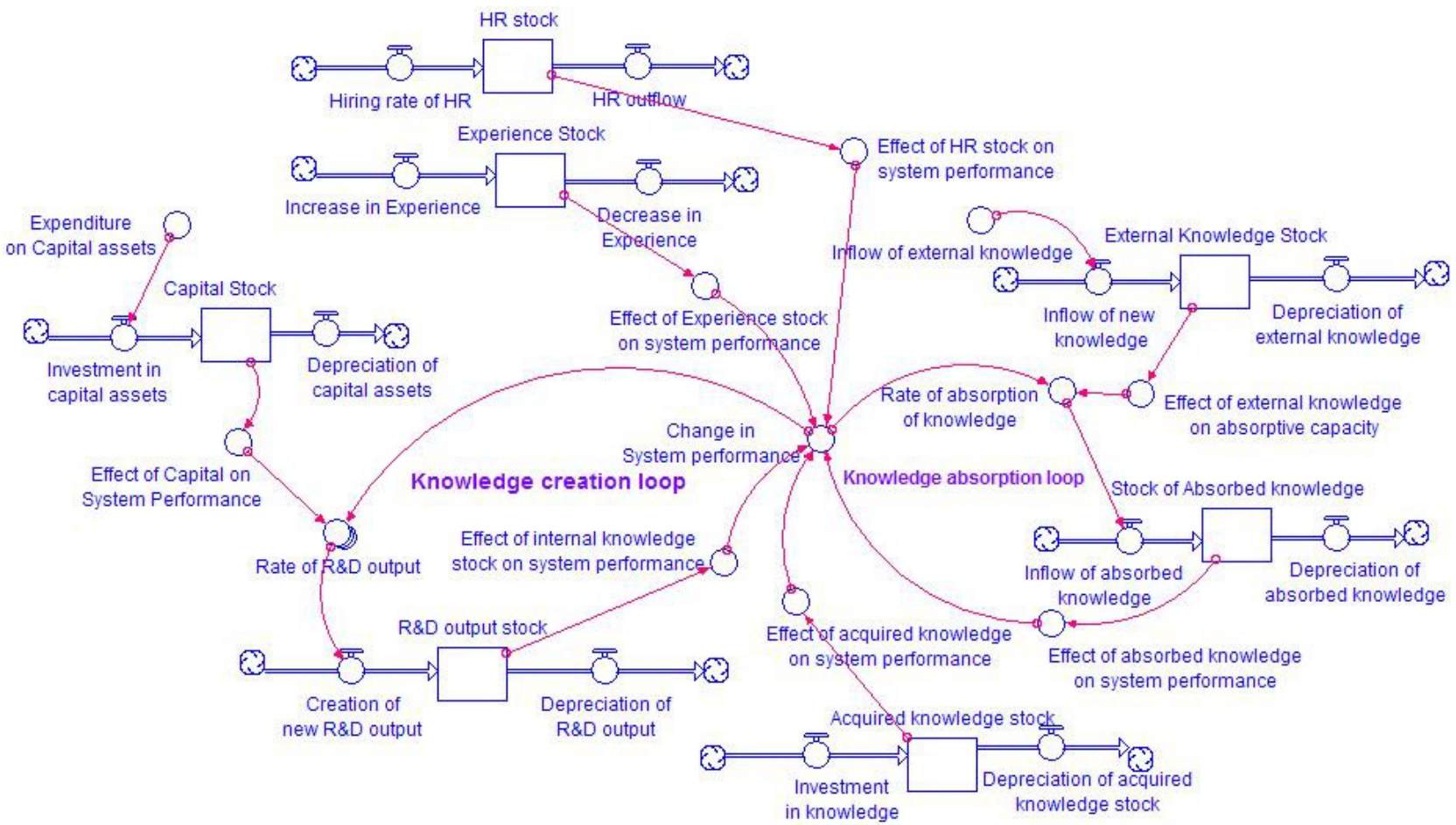


Figure 7: Stock and flow diagram of an R&D performing sector

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