The role of the discretionary grant in the dynamics of capability creation and exploitation in a public research organization:

A case Study of the CSIR

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Abstract

Public research institutions (PRIs) are tasked with generating new knowledge, as well as adding value to existing knowledge in order to come up with innovations that can contribute to national competitiveness. To this end, government provides discretionary or parliamentary grants to allow the public research institutions to execute their mandates by carrying out exploratory activities and exploitative activities in research and development.

The study aimed to establish the role of the parliamentary grant in supporting the research and development endeavours of a public research institute, with a particular focus on the management of exploration and exploitation tensions in investing the parliamentary grant. The sustainability of the PRI was sus assessed using operating profits as a proxy. The relationships between levels of investment in exploratory and exploitative actives were assessed, as was the role of the innovation system in influencing the sustainability of the PRI. We use the Council for Scientific and Industrial Research (CSIR) the largest scientific research entity in South Africa, and its operational units as a case study.

Consistent with information that is available in the literature, the data from this study shows that the discretionary grant plays a critical role as a funding stream for public research institutes, contributing to the effective execution of research and development activities of the entity. The discretionary grant is key in seeding new national competencies, and is a key initial investment in enabling the PRI to establish itself, generate outputs and outcomes that herald its competencies and thus position itself to earn other forms of income

The discretionary grant is invested for exploratory and exploitive activities. Exploratory activities generate new knowledge, which is necessary for competitiveness. Exploitative activities utilise existing knowledge to provide innovations that find utility in industries and the public sector. The manner in which the investment is split between exploration and exploitation was shown to be critical to the long term sustainability of the enterprise. Skewing investment in either exploration or exploitation alone is detrimental to sustainability.

The optimal split of the discretionary grant between exploration and exploitation was found to be dependent on several factors, to include, the technology bases of the industries in which the entity operates and the connectivity and paths of knowledge flow in the innovation systems nationally and globally.

Inability to earn other forms of income is in itself a threat to the long term sustainability, particularly in fiscally constrained environments that are typical of emerging economies. The ability to earn external income provides options for investment of the PG in building its capability base. Notable here is the fact that the absorptive capacity of the industry sector in the first place, the innovation system in which the entity operates and the connectedness of the entity within the system appear to have important influences on ability to earn other forms of income. In such cases, strategic decisions have to be made on whether the sector remains strategic enough for the country in deciding on continued investment.

While the information derived from this study is very specific to the CSIR, a combination of the data and information in the literature provides insights that are applicable to other public research institutes, particularly in developing economies.

Keywords

Public research institution, exploration, exploitation, discretionary grant

Declaration

I declare that this project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University. I further declare that I have obtained the necessary authorisation to undertake this research.

Rachel K Chikwamba

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1. Chapter 1: Research Problem

1.1. Introduction

Knowledge is a fundamental driver of innovation, which in turn is crucial as a driver of competitiveness, and ultimately long run economic growth (reviewed by Verspagen, 2005). This position is supported by empirical research, which has shown that differences in technology are a fundamental source of different growth rates across countries (Castellacci, 2008, Fagerberg et al 2007).

Public research institutes play an important role in the generation of new knowledge, as well as value added knowledge in the form of patents, as well as other research and development outcomes. Value addition to knowledge results innovations that support industries and enable delivery of services by the public and private sectors alike.

Public research institutes (PRIs) receive their initial funding in the form of discretionary grants from the government. In many cases, government grants are the only funding streams that are guaranteed for these institutions. Thus, these funds are used to generate capabilities (which include human resources, infrastructure and equipment), and to position the institution so that it can be recognised as a credible source of valuable research and development outputs. The funds also have to be used to support exploratory research and development activities, which generate new knowledge, and exploitative activities, which ultimately support innovation and ultimately competitiveness. Effective utilisation of resources in undertaking these activities will enable the institution to position itself well so that it can earn income from other sources, notably contract and royalty income. The discretionary grant thus has to be invested prudently between exploratory and exploitation activities.

Within organisations, tension exists between explorative activities that generate new knowledge and capabilities and exploitive activities which generate returns on investment (March, 1991). It is generally is widely accepted that managing this tension within an organisation is critical for optimal organisational performance (Benner and Tushman, 2003, Gupta, Smith and Shalley, 2006, Uotila, Maula, Keil and Zahra, 2009). The basis of this argument is that in resource limited environments, firms face a trade off in allocating scarce resources to either exploration or exploitation activities (Uotila et al, 2009). March (1991), suggests that this challenge exists because firms that overemphasise exploration risk spending scarce resources without any guaranteed payback, while firms that put too much emphasis on exploitation reduce the learning of new skills and generation of new knowledge, jeopardising their future competitiveness and long term survival.

The role that public research institutions play in addressing market failures and in providing commercialisable knowledge to industry cannot be overstated. Government funded non-academic research institutes are charged with undertaking research to address social and industrial technological needs, while at the same time ensuring their own growth and long term sustainability. To maintain their competitive edge, they need to continuously generate new knowledge, which is translated into applications which can generate income for long term sustainability. Thus, public research institutions constantly have to deal with the tension of balancing this dual mandate to meet national technological requirements (social obligation) while at the same time addressing the need for growth and long term sustainability (self-interest, Barnard, Bromfield, and Cantwell, 2009).

Literature is broadly available on the management of this tension in the context of a firm (Benner and Tushman, 2003, Gupta, Smith and Shalley, McGrath, 2001, 2006, Uotila, Maula, Keil and Zahra, 2009), whose primary objective is to make profit through new products arising from research and development (R and D). There is however, no readily available literature on how government funded institutes address these challenges particularly in resource limited environments. Because these institutions in many cases are not selling any finished products, and are regarded as public assets, the need to balance exploration and exploitation, particularly in the context of emerging economies is hugely amplified.

This is exacerbated by the fact that these institutions are unlikely to receive substantial increases in their grants, particularly in the fiscally constrained environments of developing economies where there are even more basic challenges. Thus proper articulation of the role of the grant, and it should be effectively managed will contribute significantly to science policy.

1.2. Research Scope

The study analyses the role of a public research institute in the context of an emerging economy. Because public research institutes receive all or part of their funding as discretionary grants from the government, the study examines the contribution of the discretionary grant in supporting the research and development activity of the institution.

This study also explored the challenge faced by government funded public research institutions in managing the exploration/exploitation tension as they simultaneously try to meet the conflicting demands of their mandates that are hinged in social obligations and self-interest. The tension has direct implications on resource allocation. Public research institutions receive resources for growth through government grants, and the outputs of these investments that are available for exploitation include scientific publications and patents. Both these output signal the ownership of knowledge assets, which attract income in the form of licensing fees, royalty income and new contract work from industrial players (Bromfield and Barnard, 2010). This knowledge base forms a valuable resource for national competitiveness.

The study attempts to associate various proxies of research and development inputs, outputs and outcomes with investment in various types research activities; exploratory versus exploitive. In order to do this, various it was necessary to work with quantitative proxies of research outcomes.

In public research institutions, two distinct processes should take place:

- Exploration, resource consuming;
- Exploitation, which draws in income (liberates returns on investment).

We study these two concepts in the context of an R and D organisation in an emerging economy. The study looks at the case study of the Council for Scientific and Industrial Research (CSIR), the leading government funded non-academic research institute in South Africa. In the context of this study, the CSIR and its entities provides a microcosm of entities operating semi-autonomously in a range of industrial sectors in an emerging economy.

We explore the interplay between exploration and exploitation by studying financial (income) and scientific outputs and the interplay between them over time.

For the purpose of this study, the term exploitation shall be reserved for activities in which the central goal is using past knowledge rather acquisition of any learning, and this sentiment is shared by others (Rosenkopf and Nerkar (2001), Vassolo et al, 2004, Vermeulen and Barkema, 2001).

1.3. Research motivation

The exploration for new knowledge and the exploitation of existing knowledge is central to the innovation process. Drucker, (1994), argues innovation is a core process for a firm, and developing innovation capability is an important strategic issue since innovation plays a key role in survival and growth of enterprises. Government funded non-academic institute play a significant role in contributing to the national innovative capability, and they are in the business of generating new knowledge even as they try to translate existing knowledge into applications that address contemporary societal needs, and they contribute significantly to the innovative capabilities of a nation. Exploration and exploitation compete for scarce resources, organisations must set explicit decision making policies for allocating scarce resources (March, 1991).

1.3.1. Importance for South Africa

The rationale of this work is based on the importance of innovation in the strengthening national competitiveness (Castellacci, 2008, Fagerberg et al 2007). Publicly funded research institutions play a key role in the building of national technological capability and ultimately economic competitiveness. According to the institutional theory of innovation, public research institutes are key components of national innovation systems and play a key role in the generation of research and development (R and D) national capabilities in innovation, (Coriat and Weinstein, 2002). The focal areas of such institutions tend to be aligned with national imperatives at any stage in the economic development of a country (Scholes et al, 20068).

South Africa appears unable to improve its position on the global competitiveness rankings. In the 2004-2005 Global Competitiveness Report of the World Economic Forum, South Africa was placed 41st out of 102 economies on the Global Competitiveness Index (GCI) developed by Jeffrey Sachs of Colombia University and John McArthur of The Earth Institute. South Africa's ranking has improved from 54 to 52th in 2012 (Martin and Schwab, 2011), which is still a worse off ranking than its 2004 – 2005 position. Clearly, interventions in technological capability are required to support public and private enterprises that contribute to economic competitiveness.

Policy makers also struggle to articulate the value of investing public funds in research and development, especially when they are faced with options to invest in basic needs like such as education and health, whose returns on investment are readily visible. Yet the literature is unequivocal on the role that PRIs have in establishing national research and development capability. It is thus important to analyse the role of the discretionary grant in supporting the research and development activities of a PRI.

1.3.2. Importance for business

At the simplest level, public research institutions provide technologies that can make the industries within their innovation systems and beyond quite competitive. The contribution of public science to research and development cannot be overemphasised. Investment in public research provides funding to address the challenges that the industries may be facing but may not be will to invest in resolving themselves due to challenges of appropriation of knowledge. It is also in industry's interest to have a clear picture of how grants made available to the PRIs through their taxes are being spent.

On another level, exploration and exploitation activities are essential for organisation, and in early works, were viewed as the classic trade-off decision between research and development: research for long run breakthrough technologies versus development of products and processes for short term gain (Garcia, Calantone and Levine, 2003, March 1991). Garcia et al, 2003, note that decisions regarding R and D activities greatly affect the fiscal and market outcomes of technologically oriented firms; research and development institutions are no different. Resource allocation actually has to be balanced in three ways; exploratory projects/processes, exploitive projects or processive and passive retention of the resources by maintaining slack levels for other purposes (Garcia et al, 2003). The success of these organisations is critical to other enterprises in their ecosystem as they provide technologies for development and industrialisation.

Decisions around exploration and exploitation matter for research managers because of their implications for resource allocation. The need for public research institutes to meet dual mandates is already challenging, and having to deal with the exploration exploitation decisions heightens this tension. Important questions pertain to the ideal balance between percentage of resources allocated to exploration and exploitation as a function of prior exploratory activities. Another question is the basis on which managers decide on resource allocation to new product development activities in the absence of external competitive forces (such as in positioning for the future).

1.4. Research Problem

Garcia et al (2003) observe that a sufficient knowledge base (or stock) is essential for supporting the coupling of knowledge with downstream profit generating conversion (i.e. development activities). Because of rapid advances in R & D, technological knowledge stocks age rapidly, and the application value declines rapidly over time. R and D institutes are thus in a constant quest to generate new knowledge.

The dual mandate of public research institutions presents challenges of the need to meet their national mandates while at the same time addressing growth, long term sustainability and legitimacy on the global arena.

This study seeks to explore how a public research institute with a dual mandate manages the tension between exploration and exploitation. Thus management decisions on resource allocation in such institutions have to deal with the balancing the tension between;

1. utilising what technologies they have available (capability exploitation) and
2. developing new technologies (capability creation) in order to position for the future.

Exploration entails investment in capability development, and yields outputs such as local and international patents, as well as journal articles published in local and international literature. Capability exploitation is manifested in many ways, to include yield royalty income as inventions are commercialised and new contract work from industry as the publications and patents signal new competences (Barnard, Bromfield and Cantwell, 2010) for industrial exploitation.

2. Chapter 2: Literature review

2.1. Theory and Literature Review

The theory that is reviewed in this study explores the role of public research institutes in the context of national economic development, and in light of their dual mandates; as organs of state mandated with carrying out research in the public interest, and their self-interest as organizations seeking identity and credibility in scientific communities locally and internationally (Barnard et al, 2009). This recognition and credibility is, ultimately important for their long term sustainability. The theoretical basis of this study is the exploration/exploitation (March, 1991) tension that is faced by firms and other organizations as they seek to remain relevant in the immediate term, and position for growth and survival in the long run, and the resource allocation implications of these challenges. We review the role of public research institutes and publicly funded research in the context of national development, the funding of public research and how such resources are allocated between exploration and exploitation. The review also focuses on the current literature on exploration and exploitation, classification of activities between exploration and exploitation, as well proxies of productivity of exploratory and exploitative research and development activities.

Models of innovation provide a range of outputs and outcomes as measures for effectiveness of innovation. In the context of this study, scientific publications and patents are regarded as products of scientific exploration and as outputs for potential exploitation, and the translation of knowledge into patents and other outcomes that earn contract and royalty incomes as forms of return on investment for public research. In a qualitative study through literature review, we examine the influence that innovation systems have on the public research institutions that operate within them.

2.2. The role of public research institutions in innovation

To understand resource allocation in a public research institute, it is important understand the role the institute is expected to play in an innovation system. Research and development activity is the primary input into the production of new technical knowledge, and that the relevant output from the R and D-based innovation process is economic growth (Link and Scott, 2005). Public research activity can be defined as scientific research performed in and supported by governmental academic and charitable institutes (McMillan, Narin and Deeds, 2000) and predominantly happens in universities and government research laboratories (Cohen, Nelson and Walsh, 2002). Fritsch and Schwirten (1999) defined publicly funded research institutions as all research institutions that are financed by the state to a "considerable degree".

PRIs play a role in domestic capacity building and ultimately in the competitiveness of a country (Bernades and Albequerque, 2003). National research institutes are mandated with undertaking research in the public interest, often the type where risks are high and industry would not support such work because of challenges in appropriating the findings and thus recoup returns on investment.

2.2.1. Addressing market failures

Development of local technological research capability is key to knowledge generation through exploration activities. Arrow (1962, discussed the properties of knowledge that make it a public good. The properties included the fact that it was not depleted when shared, once it was published, others could not be excluded from its use and finally the incremental costs of each additional user was next to nothing. Subsequently, the fundamentals of economic theory noted that competitive markets provided poor incentives for public goods as the providers of the knowledge could not appropriate the economic benefits to their creations. Dasgupta and David (1996) should non-market based incentives for scientists to engage in socially responsible activity. Scientific publications and patents are indicators of technological capacity. Patenting activity is an indicator of technological development where scientific advances are measured through scientific publications (Bernades and Albuquerque, 2003).

Government funds public research in order to support research and development work that would otherwise not happen because of the challenges of appropriating research findings and recouping costs, a key motivator for private sector investment in research and development. Acs and Audretsch (1990) (cited in Brese and Stahl, 1999) suggest that government should finance research at public research institutes to achieve the socially optimal R&D investment. It is now commonly accepted that public research institutes generate knowledge which addresses such market failures, and that the absence of such activities would result in under investment in R and D and hence a shortfall of innovation and growth from socially desirable levels (Link and Scott 2005).

A European study by Laredo and Muster, (2004) highlights that public authorities are relying more and more upon public sector research for support for their policy objectives (Laredo and Muster, 2004). In countries such as Japan, the government entered a drive aimed at doubling its public research expenditure so as to increase the public share of its knowledge base since the passing of the Basic Law as early back as 1995 (Laredo and Mustar 2004). The study also notes that key to the surge in public research expenditure were large public programs dedicated to the development of complex systems at the frontiers of technological knowledge. The programs are typically in energy, materials, telecommunications, the computer and microelectronics industries, aeronautics and space. Examples of such initiatives are the Alvey program in Britain, the European Commission's Race, Esprit and Brite and the advanced technology program (ATP) in the US (Laredo and Muster, 2004).

2.2.2. Provision of commercial innovations

Fritsch and Schwirten (1999) observed that often public research institutions are accused of ivory tower isolationism, neglecting the practical or commercial application of their research and pursuing research only for curiosity's sake. However, publicly funded research institutions are important sources of inputs for private sector innovation activities. The passage of the Bayh- Dole Act of 1980 in the US resulted in public research institutes, notably universities, playing an increasingly important role in provision of commercial innovations and technologies (Link & Scott, 2005).

In a study carried out in Europe (Laredo and Mustar, 2004), universities and government sponsored laboratories were noted to have become essential to private firms, with notable growth in numbers of collaborative agreements between these institutions. In that study, the reasons for the increasing importance of public sector research included the radical repositioning of science and technology policies away from the direct support of large firms but rather towards small and medium enterprises (SMEs). Fritsch and Schwirten (1999) examined the contribution of public research to private sector innovation through a study of how public research institutions in Germany developed relationships with manufacturing firms and with each other. In their analyses, the authors showed that non-university research institutions had the highest rate of cooperation (91%) with industry.

Nalin, Hamilton and Olivastro (1997) studied the increasing linkage between US technology and public science. In that study, they found that in 1993- 94, 73% of the scientific papers cited by US industrial patents were from public science sources while only 27% were from industrial scientists. Thus, developing innovation capability in the public arena is an important strategic issue since innovation plays an important role in the survival and growth of enterprises.

2.2.3. Facilitating knowledge flow/ Other benefits

Griliches (1995, p63) notes “the level of productivity achieved by one firm or industry depends not only on its research efforts but also in the general pool of knowledge available to it”.

Fritsch and Schwirten (1999) also assert that public research institutions build up their knowledge bases by absorbing and accumulating knowledge created elsewhere, and but also through generating new knowledge through conducting their own research. They diffuse knowledge into the economy via many different channels, (Fritsch and Schwirten, 1999, Martin et al, 1996):

1) Training skilled graduates
2) Creating new scientific instrumentation and methodologies
3) Forming networks and stimulating social interactions
4) Increasing the capacity for scientific and technological problem solving
5) Creating new firms

Public research institutes do not carry out their research and development in isolation, but are influenced by the environments within which they operate.

2.3. Systems of Innovation

The role of capabilities in economic development was also reviewed by Fagerberg and Srholec (2008). In this work, they identify four different types of “capabilities”: the development of the innovation system, the quality of governance, the character of their political system and the degree of openness of the economy. Of these four, innovation systems and governance are shown to be of particular relevance to development. Innovation systems are particularly important in the context of the current study. Countries are not homogeneous in technological capability, regardless of possible access to technology through various globalisation processes (Bernardes and Alberquerque, 2003).

Rebeiro, Ruiz, Bernades and Albuquerque (2012) provided evidence that more a broad science and technology infrastructure is necessary for development, and that this necessity grows over time because to catch up, a country needs to improve its innovation capabilities. Over time, the scientific content of technology is increasing, emphasising that the need for greater and deeper scientific infrastructure is necessary to supportive innovative activities. It is deficiency in scientific infrastructure which weakens knowledge transfer between science and technology, and thus there is no impact on economic growth (Bernardes and Alberquerque, 2003). The study found strong correlations between scientific and technological productions and capital income levels.

Freeman (1987) used a combination of on institutional combined with evolutionary theories to define an innovation system as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies", and this has led to the Innovation System (IS) approach.

2.3.1. National Systems of innovation

Public research institutions are a key part of the National System of Innovation (NSI), a country's institutional framework which includes the agents involved in translation of innovation and imitation into economic growth (Ribeiro, Ruiz, Bernades and Albuquerque (2006). The system includes firms, universities, research institutions, financial systems, and government departments, and plays a key role in the establishment of national capabilities. According to Edquist, (2010), systems of innovation provide new knowledge, or integrate existing knowledge, build up competence through education and training of human capital, facilitate articulation of demand for new products, and facilitate the creation of new and changing of existing organisations to support new fields of innovation. Systems of innovation are a key player in the national production of scientific outputs. Bernardes and Alberquerque (2003) suggest that there is a threshold level in scientific production beyond which the technological sectors efficient use of scientific output increases. The interplay between science and technology appears to work better in countries above this threshold. Below this threshold, there is a lack of critical mass.

The functions of the innovation system include (Ref);

- Creation of new knowledge
- Guiding the direction of search processes
- Supplying resources (financial, human)
- Facilitating the creation of positive external economies (in the form of an exchange of information, knowledge, and visions)
- Facilitating the formation of markets

Salter and Martin (2001) suggest that a key benefit of public financing of research is that there are "spill overs from government funding to other activities such as industrial R & D". Such spill overs are meant to enhance the productivity of a firm or industry by expanding the general pool of knowledge available to it. Two main forms of spill over have been identified

i) Geographical and cross
ii) Cross sector spill overs

Geographical spill over concept fits in well with concept of innovation systems. There are benefits for firms within proximity of research centres. In a study analysing US patents, Hicks and Olivastro (1998), showed that US patents tended to cite papers produced by local public sector institutions, with over 27% of the references cited as being state of the art coming from the institutions within the US state where the firm operates. Narin et al (1997) also demonstrated national patterns in the citation of local research in industrial patents, showing that German firms filing patents in the US were 2.4 times more likely to cite German public scientists among their references than any other nationalities. However, these geographical effects were found to be not so universal (Narin et al, 1997).

The study by Saxenian (1994) of Silicon Valley and Route 128 emphasized the importance of geographical spill overs, concluding that local institutions (including the research infrastructure), profoundly shaped a region's capacity to innovate. This view emphasizes the person embodied nature of knowledge, and importance of face to face engagements in knowledge transfer.

Personal interactions are untraded, and create interdependencies that form collective property of the region and facilitate the expansion of the range of activities of the regional actor. Personal links are thus important for the research process.

2.3.2. Technological Systems of Innovation

Innovation systems are a very important determinant of technological change. Lundvall (Ref) also suggests that a promising direction to better understand innovation systems is to study technological systems, indicating that there is value in thinking in terms of technological systems. This author defined a technological system is a combination of interrelated sectors and firms, a set of institutions and regulations characterizing the rules of behavior and the knowledge infrastructure connected to it. Hekkert et al, 2007 labelled the technological systems of innovation as Technology Specific Innovation Systems (TSIS). Lundvall notes that most innovation policies are well suited when it comes to supporting existing technological systems, but much less when it comes to stimulating the creation of new ones.

2.3.2.1. The role of innovation systems in facilitating connectedness

Innovation systems facilitate connectedness between all players in an industrial or service sector. Meyer, Kramer and Schmoch (1998) demonstrated that collaborative research and informal contacts are the most important forms of interaction between public research (in the case, universities) and industry. Academic researchers gain funding, knowledge and flexibility through industrial funding. Such collaboration between industry and public research involves two way flow of knowledge, and informal discussion is preferred to publications. The strength of industry public research is dependent on the absorptive capacity of the industry and the innovation system.

2.4. Capability requirements for innovation

Kim, (1997), introduced the concept of technological capability as “the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technology” Technological capabilities have always been a fundamental component of economic growth and social welfare (Archibugi and Coco, 2004). Technological capabilities of a nation are composed of a variety of sources of knowledge and of innovation, to include formal and tacit knowledge. The various sources of technological capabilities are likely to be complementary than interchangeable. Technological capabilities include ability to create technology, technological infrastructure and human skills. First rate infrastructure in the absence of a sufficiently qualified labour force will be useless and vice versa.

2.5. Funding of public research

Financial resources are a key input in supporting public research. Typical Frascati manual (OECD, 2002, Brent and Pretorius, 2009) inputs include financial and human resources. Walwyn and Scholes (2006) noted that public research institutes (PRIs) support the research and development operations using a variety of funding models. Some PRIs are wholly funded by government grants, while on the other extreme, others are almost entirely funded by contract research or project or project funding. According to Walwyn and Scholes (2006), in a study carried out by the CSIR , the ratio of grant to contract income was found to range from 72% (Institute for Research in Construction, National Research Council of Canada) to 25% (TNO Nutrition and Food Research Institute, the Netherlands). Grant funding plays a critical role in that it is the income stream with the highest probability of being secured

According to an OECD report (2003), the trend in the 1980s was most certainly towards increased contract and reduced institutional or grant funding. The reasons given for this change in the funding of PRIs was that grant funding was not considered sufficiently competitive; such that by introducing a higher proportion of income from competitive funding streams, it was argued that the overall quality, efficiency and output from PRIs would be increased. The evaluation processes to access competitive funding were based on peer review, which ensure higher research quality. In addition, contract income was supposed to increase the relevance of the PRIs, since left to their own devices, they tended to focus on research that was not necessarily connected to societal or industrial needs. Finally, contract funding was deemed to spread the loads of maintaining a country’s R&D

infrastructure and capacity. PRIs become less reliant on government funding and can afford to retain the same capacity at lower overall cost to the public sector (OECD).

Lutjeharms and Thomson (1993), thought that the model had failed in South Africa, concluding that this transformation had failed to achieve the key intended objective, which was to build a support service for the private sector, but in the process had severely damaged 'scientific endeavour within the CSIR and in the country as a whole'. According to Walwyn and Scholes (2006), in such a competitive environment, the institution is required to focus its expertise, to build and retain more specialized resources within niche areas. In addition, the culture of the institution, including its business model and employee profile, shifts from a public sector or public service culture to something akin to a private sector contract research company. Proponents of this view are supportive of public research institutes receiving greater support in the form of the discretionary grant.

A concern in the literature is that the more contract work the entity gets, the more this might compromise the entity's ability to undertake quality research and development work, or compromise the ability to invest time and resources into exploratory but directed research work which generates new knowledge, as well as the rigour (Lutjeharms and Thomson, 1993) with which this can be done. In fact, at the heart of this argument, is that too much service oriented work should not be the business of a PRI, as this should be done by the consultancy agencies or private companies in the system (Walwyn and Scholes, 2006).

A counter argument to this is that knowledge based service work can create even more fundamental research as it unravels new challenges that the various clients face. One could also argue that if the work of the PRI were not of a good enough quality, they would not experience expansion in contract research work from new and existing customers. In a situation where a PRI has a strong and stable external income stream, the PRI can then use contract income to support some of their basic research work, strengthening their knowledge/capability base to be able to attract even more contract work. The virtuous cycle here is between contract/service work and research and development.

2.6. Return on research and development

Literature on the subject of return on scientific investment for public research is limited. Extensive work has been presented on return on investment made in research and development for commercial firms, where tangible products are developed and sold on open markets (Uotila et al, 2009). Scientific publications are an output indication, which is closely associated with public research and development expenditure input (Archibugi and Coco, 2005).

Czarnitzki and Licht, (2006) attempted to estimate the impact of public R and D grants on private sector firms' R and D and innovation inputs. This team used the relation between publically funded R and D and innovation output to benchmark impact of public money on investment in private firms. Data from this study showed that there was additionality in public R and D grants with regard to innovation output measured by patent applications.

Ravenscraft and Scherer note that in measuring the returns to research and development, time is critical factor. They noted that the completion of an R & D project took an average of about 3 years, and once technical success is achieved, it takes time to launch and build up a new product's sales in the market and to replace older production processes. For an R & D organisation, however, the returns are not based on the sales of products, but rather on the licensing and royalty incomes as well as additional contract research from industry.

2.7. Proxies of research and development indicators

Salter and Martin (2001) summarised evidence of economic returns to the state's investment in science and its significance in developed countries. Yet those who face decisions on how to spend limited public funding face huge challenges. (The benefits of funding public research are not always as obvious as those funding education or public health. The benefits are both direct and indirect, although there are some flaws/gaps in the evidence.

The gaps result from the conceptual problems of understanding the nature of research and the form of its outputs- whether it is information or knowledge (codified or tacit), or whether trained people and new platform and instrumentation are as important. (Martin and Salter, 2001) There are methodological challenges in the approaches used to analyse and assess the benefits of research, which range from economic tools such as production functions to using scientific papers and patents and their level of citation as links between science and technology.

The performance measurement indicators of research and development effectiveness follow a range of models of innovation. In this study, performance measures are concerned with inputs, outputs and outcomes (Jaffe, 1998). The linear model of innovation is one of the first conceptual frameworks developed in an attempt to understand the relationship between science and technology and the economy. According to this model, innovation starts with basic research, followed by applied research and development which leads into production and finally diffusion (Jaffe, 1998, Langford et al, 2006). In this model, the indicators operate at three levels of; measures of (direct), proxies for (indirect), or correlates of (linked by some statistical hypothesis) the phenomenon under analysis (Langford, et al, 2006). Input measures include financial and other resources, but they have limitations in that they concerned more with intent than with success. Landrey et al (2002) suggest that the awarding of competitive peer reviewed research grants is perhaps a good input proxy, but still a measure of promise and not a guarantee of the outputs promised. Industry sponsorship investment or contract work can also be used as an input proxy for industry-driven collaboration, the ‘market pull’ driver of knowledge transfer (Landrey et al, 2002), and possibly relevance of research and development work to industry. It is on this basis that income streams are such as the discretionary grants are considered as inputs in the context of this study.

Output and outcome indicators on the other hand deal with results. These include publications, patents and citation data, which are widely used and available output proxies (Langford et al, 2006). Available, outcome (impact) indicators are common proxies for innovation, and are aligned to the pathway passing through technology licensing and spin-off which are aligned with the linear model. Combined with input measures of R&D funding, output measures of publications and citations, outcome indicators such as licenses and spin-off formation are clearly aligned with the linear model of innovation, an approach that is widely criticized for its failure to explain key features of innovation such tacit knowledge, industrial science, non-science based technology, industrial differences with respect to scientific requirements. It also excludes consideration of the fact that sometimes technology precedes the science that explains it (Nightingale, 2004).

However, the most commonly used outcome proxies are implicitly linear. Notable are patents and patent analyses, which are based on the assumption that output proxies of explicit knowledge (patents and papers lead to increased knowledge that ultimately yields commercial benefits.

Pavitt (1998) also observed that patents granted to universities as a measure also provides a limited view of the contribution that universities or research institutions make to technical change. Because the criticism of these available and widely used indicators does not suggest that they are not valuable, but that they provide partial view of reality (Langford 2006, Pavitt, 1998).

2.7.1. Role of proxies as signals of capabilities

Patents are considered a measure of technological advancement, while scientific advances are measured through publication, but both signal ownership of knowledge assets.

Patents are codified evidence of capability, and can be used to signal competence. Patents fulfil entry requirements to communities of science where scientific outputs are used as evidence that the organisations should be taken as credible members (Bromfield and Barnard 2010) of knowledge communities/networks. Because patents provide codified evidence of capability, they can attract opportunities for exploitation of R&D outputs and capability, their licensing leading to royalty income, license fees and more work in the form of contract research and development work from industry. They also strengthen the reputation of the holder in an industry (Muller and Penin, 2006). All measures of national capabilities use patent statistics as a solid indication of natural innovative capacity (Archibugi and Coco, 2005).

There is empirical evidence that creating and commercialising IP has become an imperative of public research institutes. Acs and Audretsch (1990) (cited in Brese and Stahl, 1999) suggest that government should finance research at public research institutes to achieve the socially optimal R&D investment. Brese and Stahl (1999) also suggest that publicly funded research is expected to be utilised by the private sector businesses for industrial innovations. Journal articles are the currency for exchange of knowledge in scientific community (firm and university researchers, Dicks, 1995) strengthen reputation as innovator (Muller and Penin, 2006) and important precursor for partnering.

Bernades and Albuquerque (2003) note that there is a mutually beneficial relationship between patenting and publication associated with higher levels of economic development.

2.8. Exploration and Exploitation

Exploration and exploitation have emerged as the twin concepts underpinning organizational adaptation (Gupta, Smith and Shalley, 2006). Organisations generate competence in the form of either exploitation or exploration (March, 1999). Gupta et al, (2006) suggest there is general consensus that exploration refers to learning and innovation in pursuit of new knowledge (Gupta et al, 2006), but ambiguity prevails on the definition of exploitation. The authors suggest that there is lack of understanding on whether exploitation refers strictly to the use of past knowledge, or whether it also refers to acquisition of a different kind of knowledge from that associated with exploration. Baum, Lee and Usher (2002) suggested that exploration refers to learning gained via local search, experiential refinement, selection and reuse of existing routines, whereas exploration is learning acquired through processes of concerted variation and experimentation. He and Wong, (2004) defined exploitative innovation as aimed at improvement of existing domain markets and exploratory innovation encompassed technological innovation aimed at entering new product markets. The common thread here is that learning, acquisition of new knowledge is central to both exploration and exploitation. Gupta et al, (2006) concluded that both exploration and exploitation involved learning of different degrees and types.

However, in a study focusing strictly the R and D process and patenting activity, Rosenkopf and Nerkar (2001) reserved the term exploitation for activities in which the central goal is using past knowledge rather acquisition of any learning, and this sentiment is shared by others (Vassolo, Anad and Folta, 2004, Vermeulen and Barkema, 2001).

2.8.1. Exploration and exploitation tensions

Crossan, Lane and White (1999) outlined a conceptual model of exploitation and exploration that highlighted the dynamics between the two processes. The study also highlighted the tensions between the two processes. Exploration and exploitation dynamics are crucial to organizational learning and change. Gupta and co-workers (2006) explored several dimensions of interaction between and exploitation, including continuity versus orthogonality, ambidexterity versus punctuated equilibrium as well as duality versus specialization.

2.8.1.1. Continuity versus orthogonality

The ease with which an organisation can pursue both exploration and exploitation depends on whether or not they are regarded as complementary or competing aspects of organisational decisions or actions. This aspect is investigated by Gupta et al, (2006), and they referred to it as continuity versus orthogonality. An interesting argument put forward by this group was the possibility of being locked up in a failure trap because often, exploration leads to failure, the more the failure, the more the exploration. The success trap also once established, was also self-fueling, exposing the enterprise to risk due to lack of generation of new knowledge for the future. The group concluded that under conditions of resource scarcity, the two concepts were mutually exclusive. Also, within singular domains or narrow subsystems, the two could also be mutually exclusive.

2.8.1.2. Ambidexterity versus punctuated equilibrium

Ambidexterity builds on the premise by March (1991), that an organisation requires both exploration and exploitation to achieve long term success. Ambidexterity refers to the synchronous pursuit of both concepts, via differentiated loosely connected business units or individuals, each of which specialises in one or the other (Gupta et al, 2006, Benner and Tushman, 2003). Burgelman, (2002), defined punctuated equilibrium as temporal separation of the two concepts, as compared to organisational differentiation, and proposed that cyclical pursuit was a more viable approach than simultaneous pursuit of both. Gupta et al 2006 concluded that whether ambidexterity or punctuated equilibrium was appropriate as a balancing mechanism for exploration and exploitation depended on the context. When applied to a single domain, with exploration and exploitation viewed from opposite ends of the continuum, then punctuated equilibrium was most appropriate. Multiple domains with the two concepts viewed as othorgonal, ambidexterity would be the appropriate adaptation. Gupta and co-workers also concluded that ambidexterity or punctuated equilibrium may be easy being easier to achieve at organisational level than at individual or unit level.

2.8.1.3. Duality versus specialisation

This comparison finds basis in the need for balance between exploration and exploitation as suggested by March (1991). The argument put forward in this regard is how under certain circumstances, it may be feasible to dedicate the organisation or the system to one or the other. This works where markets are involved, where some organisations do exploration, others exploitation but the market then ensures balance. This concept is like ambidexterity on a broader sense.

2.8.2. Mutually reinforcing nature of exploration and exploitation

In examining the tension between exploitation and exploration, Holmqvist (2004) observed that exploitation can become a cause for exploration, and exploration a cause for exploitation. This observation is rooted in the concept that organisations learn better when they do things repeatedly, and risk the possibility to get “locked in” due to the self -reinforcing nature of learning. By creating rules for exploitation or exploration, organisations can be recognized when they have gone into ‘lock-in’ mode. Thus dissatisfaction with exploration will lead to exploitation and vice versa (Holmqvist 2004).

Balance between exploration (incremental change) and exploitation (radical change), is at the heart of organizational adaptation (Gavetti and Levinthal, 2000). Aberthy (1978) suggested that a firm’s focus on productivity gains inhibited its flexibility and ability to innovate; effectively a firm’s decline was directly linked to its efficiency and productivity efforts. The reason for this was that the competitiveness of a firm over time is not simply rooted in its efficiency, but as well in its ability to be simultaneously efficient and innovative. The ability to be both efficient and innovative, particularly in a rapidly changing and competitive environment, is the basis for the dynamic capabilities.

2.9. Categorizing Research into exploration and exploitation

In order to assess any associations between proxies of research and development, it is important to use standard approaches in categorising research and development. The OECD Frascati Manual (6th Edition, 2002), aims to provide standards for collecting research and development statistics, so that the statistics are comparable and reliable. Statistics are used as indicators for evaluating government programmes, even though they may not be completely adequate. Frascati Manual (6th Edition, 2002), categorises research into Type A, B, C, D, E.

Type A research focuses on the discovery of new knowledge, which contributes to the building of a scientific or technological platform. This knowledge is at a more fundamental level of understanding (not yet applied). Because Type A research seeks to acquire new knowledge aligned with national imperatives, the initial outputs of such research included mostly publications, and for the purposes of this study will be referred to exploration as it is well aligned with March (1991)'s original definition of exploration.

Type B research focuses primarily on experimental development, such as the development of a new product, process or service using existing knowledge. It also generates new knowledge, but such knowledge is not at a fundamental level and can be considered as incremental innovation, and is quite synonymous with March (1991)'s definition of exploitation. Outputs of Type B investments include, for the CSIR patents (a whole value chain from new invention disclosures and through examination, international patents granted) and technology packages. Technology packages are a combination of new and existing information, through clear steps to provide a process, product or service. Some of the processes may be totally novel, but instead of patenting (thus publicising), the CSIR or other entities may internally register these as industrial or trade secrets. Both patents and technology packages are licensed and they earn royalty income. Technology packages, other non-specifically documented know-how and patents are the basis of which public research institutes earn contract work and perform non routine services.

Type C work focuses on technology transfer, industrialisation and knowledge based services. However, the services in this category are not routine, routine services are categorised as Type D, while Type E is portfolio management.

The Frascati manual points out that possibly the greatest source of error in measuring research and development is the difficulty in establishing the cutoff point between experimental development and related activities required to realize innovation, and that errors in this respect can be quite significant (OECD; Frascati Manual, 2002).

2.10. Exploration and exploitation in decision making

Literature suggests that balance between exploration and exploitation is key to the firm's survival, particularly in knowledge intensive environments. External competition ramps up emphasis on exploration activities to compete for market opportunities and stay ahead of the competition. Knowledge is a resource critical for product, process and organisational innovation, as well as a resource for application, acquisition and calibration of other resources for the innovative R & D objectives (Garcia et al, 2003). Technological knowledge acquisition is the primary objective of both research (exploration) and development (exploitation). Kogut and Zander (1992), assert that the generation of new knowledge and the ability to recombine existing knowledge to exploit existing opportunities is critical to the creation of sustainable competitive advantage. Yet too much emphasis on either activity can lead to the demise of an enterprise. Managing resource allocation to either of these two activities is thus a strategic managerial decision.

The value of proprietary knowledge diminishes, to the extent that it is an asset. Garcia et al (2003) propose four factors that affect the relative value of innovative knowledge to the organisation and these include:

i. Availability of resources for exploration and exploitation activities as a function of past new product development performance;
ii. Exogenous competitive forces;
iii. Aging or discounting of knowledge through decay or shelving;
iv. Adaptive capacity (willingness, flexibility of an organisation to value innovative knowledge).

Enterprises must thus continuously seek new knowledge with the hope of being able to exploit it for sustainability and future return on investment. These issues are equally applicable to a public research entity as they are to a private firm.

2.11. Definition of Terms

Against the background literature provided about, it is appropriate to define some key terms in the context of this study.

Exploration: Research that focuses predominantly on the discovery of new knowledge and create new capabilities. The new knowledge can also be directed for a specific use, but the exact process or technology in which it would be used may not be clear at the outset. In this study, this work is synonymous with basic research and Type A research in Frascati classification of research.

Exploitation: Research that focuses predominantly on the application of knowledge (discovered internally or acquired from external sources) and existing capabilities in the development of new products, processes or services. This work may also generate new knowledge. In this study, this work is synonymous with applied research and Type B/C research in Frascati classification of research.

Capability: In the context of this study is an encompassing term referring to skills, human resources, instrumentation and research and development infrastructure.

3. Chapter 3

3.1. Research question

The key question in this study is to understand the role of the parliamentary grant as a key input in supporting a public research institute in fulfilling its mandate. Key to this analysis is to understand the resource allocation between exploratory and exploitative research, and to establish whether these activities are accompanied by the expected output and outcome proxies. The objective analyses of these issues within a research an active enterprise will shed some light on how prudence in investment in these aspects can lead to a sustainable model for funding of public research.

3.1.1. Specific research questions

The specific research questions to be address by this study include;

What is the contribution of the parliamentary grant as a key input into the research and development activities of a public research institute?

How is the discretionary or parliamentary grant invested between exploratory and exploitative activities within the enterprise and its units?

Is there an optimal split of discretionary grant between exploratory and exploitive activities?

Is there a correlation between outputs such as scientific publications and investment in Type A or exploratory research and outputs such as patents, technology packages and royalty income with translational Type B or exploitative research?

What is the influence of the maturity of the innovation system within which a public research institute operates on the role the PRI plays play in both basic and translational research?

Is the age of a unit a factor in its ability to generate outputs and become sustainable?

3.2. Research Hypothesis

Against the literature reviewed above, the following hypotheses are formulated.

3.2.1. Hypotheses

Hypothesis 1

The role of a public research institute is to translate basic research into value added innovations. To this end, the discretionary grant or parliamentary grant (PG) provided by government is a necessary initial investment to generate knowledge, in the form of publications, knowledge with added value such as patents, which are licenced to earn contracts and royalty income

H1a: Funds from parliamentary grant are used to generate knowledge, which is disseminated in the form of publications, so that published scientific articles are correlated with the parliamentary grants received by the institution.

H1b: Funds from parliamentary grants are used to create knowledge with added value, such that patents granted to the institution are correlated with parliamentary grants received by the institute.

H1c: Patents and publications generated by institution herald the presence of capability, which attracts income in the form of contracts and royalties, such that contract income and royalties are correlated with the parliamentary grants received by the institute.

Hypothesis 2

Public research institutes are continuously seeking to create new knowledge in order to meet future needs even as they strive to exploit existing technologies to address current developmental challenges. The investment of the discretionary or parliamentary grant (PG) between capability creation (exploration) and capability exploitation is critical to the creation of a virtuous cycle of capability creation and utilisation reflected as enterprise sustainability measured as operational profits.

H1a: There is a negative correlation between increasing proportion of the parliamentary grant invested in Type A research and profitability

H2b: There is a negative correlation between increasing proportion of the parliamentary grant invested in Type B research and profitability

H2c: There is an optimal split between investment into exploration and exploitation for sustainability.

Hypothesis 3

Generation of new knowledge is heralded as scientific and engineering publications. Publications should thus be a predominant output in environments where there is heavy investment in exploitive R and D activities (fundamental, Type A). As such, there should be a strong correlation between investments in Type A research and scientific and engineering publications.

> H3a: There is correlation between investment of the parliamentary grant in Type A research and development activities and scientific publications, new invention disclosures

Hypothesis 4

Addition of value to basic knowledge in the process of research translation results in patents, which are proxies for knowledge with application. Patents should thus be a predominant output in environments where there is heavy investment in exploitive R and D activities (translational, type B). As such, there should be a strong correlation between investment in type B research and patents, licence agreements and royalty incomes.

> H4: There is correlation between investment of the parliamentary grant in Type B research and development activities and patents, technology packages, spin out companies and technology licenses.

Hypothesis 5

Creating capabilities for the future requires spending financial and human resources for future returns, while exploiting the same capabilities earns such institutions income from royalties and contracted work from the private sector. These two processes are occurring simultaneously and constantly over time, and are possibly reinforcing each other. This is the basis of our fifth hypothesis, H5.

> H5: Exploration and exploitation are occurring simultaneously, and are mutually reinforcing.

4. Chapter 4

4.1. Methods

The research question in this study focuses on understanding the role of the parliamentary grant in supporting a public research institute in fulfilling its mandate. The study further analysed the investment of the parliamentary grant in capability building or exploration (resource consuming) and capability exploitation (outputs, income generating), and how the choices made in this decision can result in a sustainable model for funding in a public research institute. The study is centered on a case study of the Council for Scientific and Industrial Research (CSIR), a leading public research institute in South Africa. This was be achieved through the systematic evaluation of trends in income streams, evaluation of parliamentary grant allocation to various (explorative vs exploitative) activities and the relationships between financial investment in various categories of research and the outputs and outcomes using various proxies.

4.2. Approach

4.2.1. Case study approach

In the management sciences, a small number of cases are analysed in depth rather than attempting to summarise broad numerical information (Monaghan, 2003). Case studies afford the best tool to examine directly what happens with a specific set of circumstances. Data from case studies provide data to support the findings of econometric studies or surveys. Their key limitation is, of course, that they yield only a narrow picture of reality.

However, the challenge with this approach is that it is typically difficult to make broad statements based on the findings. This is basis for criticism of the reliability and validity of the case study approach. Flyvbjerg (2006) notes the following as the merits of a case study approach as a research method:

- General propositions and theories can be made on the basis of specific case studies.
- Utilised correctly, are not biased towards verification, and do not confirm the researcher's preconceived notions.
- Cases studies generate practical knowledge of equal or even greater value than theoretical knowledge.

In addition, Eisenhardt (1989), argues that the case study process can highly iterative and strongly linked to data, such that the resultant theory from case study research is generally novel, testable, and empirically valid.

Quantitative research methods are often depicted traditionally as the traditional scientific approach to research which puts emphasis on a “systematic and methodological process that places considerable value on rationality, objectivity, prediction and control” (Walker, 2005). This method involves the collection of numerical data that, in turn, can be subjected to statistical analysis. Parahoo (1997) and Huitt (2001) identify three levels of quantitative research, descriptive, correlational and experimental. The following two are relevant to this study:

- Descriptive research provides an account of the characteristics of individuals, groups or situations; the researcher attempts to describe, in numbers, what is actually occurring.
- Correlational research examines the links (or relationships) between variables without introducing an intervention; the purpose of this type of study is often to predict the level of one variable by knowing the level of a second variable. The strengths of correlation analyses described by Williams (2007) include the fact that the approach is well suited to study the breadth of a phenomenon; and predictive relationships can be established. However, the major weakness of correlation analysis is that the investigation cannot produce in-depth descriptions, or causality between two variables.

This study starts off with descriptive work, which is research that is designed to analyse and explain what is going on with a given topic. In this case, we are analysing over time, the CSIR’s annual income, split into various categories, and the CSIR’s outputs as described below. Thus with this aspect we will seek to establish a simple trend analyses. The **input variables** included annual financial information in the form of;

- total annual income
- core parliamentary grant (PG)
- Type A PG investment
- Type B PG investment
- Type C PG investment
- contract income from the public and private sectors
- number of staff
- Age of unit

The **output variables** will include;

- publications
- new invention disclosures
- international patents granted

- patents licensed
- technology packages
- royalty income
- net profit

Note: The number of staff in each unit was used to normalise data to facilitate comparisons, as the number of staff was considered an important determining factor in the number of outputs that a unit could generate. It was also quite challenging to establish with accuracy the age of some units as some units evolved over time and the content or focus of their work changed significantly. The CSIR as an entity also reconfigured its competencies over time, merging and splitting some units, thus the best estimates are used based on available organisational literature.

Next, the study sought to establish relationships between the inputs and outputs.

4.3. Population

The population in this study included public research institutes in South Africa, of which the CSIR is one.

4.3.1. Unit of analysis

4.3.1.1. Sampling method and size

The CSIR as the leading government supported research and development institution in South Africa, and certainly is the largest research and development (R&D) organisation in Africa and accounts for about 10% of the entire African research and development budget (http://en.wikipedia.org/wiki/Council_for_Scientific_and_Industrial_Research).

4.3.1.2. Sample

The CSIR will be the sample organization for the case study.

4.4. Data Collection: Analyses of Income streams

The CSIR is a public research institute which implements research and development work in operating units as shown in Table 1. Each unit has a generally unique technology focus area, although there are minor overlaps. The CSIR operates on a mixed income model, and its funding streams include the discretionary (or parliamentary grant; PG), which is received from parliament through the Department of Science and Technology, contract income, which is earned by the organisation for work done on contract for entities in the public and private sectors. The CSIR also earns royalties from technologies and patents licenced to local and international private and public entities. In this study, analysis is made of the role the discretionary grant in knowledge and technology generation, and the related outputs. The amount of discretionary grant allocated to each operational unit is referred to as core PG. Generally, the discretionary grant or core PG is allocated on the basis of installed capacity, and is approximately a third of the business unit's operating expenses.

Table 1: CSIR units that operate in research and development, the unit names and configuration have evolved over time

Unit	Acronym	Original Name	Recorded Start Date of Progenitor Center	Technology Focus	Age in 2012
Biosciences	Bio-sciences	ChemTek/FoodTek	1988	Life Sciences/ Biotech	24
Built Environment	BE	Institute for Construction Research	1946	Infrastructure design, planning, technologies	66
Defence, Peace Safety and Security	DPSS	Institute for Defence Research	1965	Defence and Security	47
National Laser Center	NLC	National Laser Center	2002	Photonics and optics	10
Natural Resources & Environment	NRE	Institutes for Water and Forest Research	1958	Ecosystems, resource use, sustainability	54
Material Science and Manufacturing	MSM		1988	Material Science and Industrial Research	24
Meraka	Meraka	ICT Tek	1988	ICT	24
Modelling and Digital Sciences	MDS	MDS	2006	Applied Mathematical Sciences	6

Data on the three income streams was obtained from the CSIR finance department. For the CSIR level data, information was collected from 1945 until 2011. The raw data is shown in Appendix 1. For individual units, similar data as well as information on the split of PG investment into Frascati categories was collected from 2005 to 2011 was also collected, and the raw data is shown in Appendix 2. All financial data were converted to 1995 Rand value as shown below. Annual profits after all unit operational costs are considered an indicator that a unit is conducting its business sustainably. Profits are also recorded in 1995 Rand value.

Table 2: CSIR units that operate in research and development, they have evolved over time from their original configuration

Unit	Acronym	Average Annual Profit (1995 Rm)	Group
Defence, Peace Safety and Security	DPSS	14.105	Sustainable
Meraka	Meraka	6.148	
Material Science and Manufacturing	MSM	3.662	
[a]Modelling and Digital Sciences	MDS	0.757	
Natural Resources & Environment	NRE	1.652	Not Sustainable
[b]Built Environment	BE	4.438	
Biosciences	Bio	-0.887	
National Laser Center	NLC	0.267	
CSIR R&D Units Pooled	**CSIR**	**30.143**	**Sustainable**

Note:

[a]MDS is very young and has an upward trajectory in growth of revenues and profits, and is thus considered sustainable

[b]BE has larger average annual profits than MSM, but has a steeper downward trajectory, and is thus classified as not sustainable.

4.4.1. Criteria for grouping of units

Annual profits are recorded for each unit; some units are more sustainable, on the basis of operational profits recorded, while others are less sustainable. The units were grouped into four categories as follows:

i. Sustainable groups have a positive profit margin, and a generally upward trajectory in terms of growth of revenues in the period under study.
ii. Not sustainable groups have small positive or negative profit margins, as well as a stagnant or downward trajectory in growth of total revenues (Figure 1).
iii. Both groups have a young entity within them, and while this was difficult to judge, the entities showed clear trajectories (up or down) for the period under study.

4.4.2. Calculation of 1995 Rand Value

The financial data in this study were converted to 1995 Rand value.

Calculations were based on the procedure followed by Walwyn and Scholes, (2006), which used the same data global CSIR financial data set but is unrelated to the concepts explored in this study. The multiplier to get from the current year to the 1995 Rand value is obtained by the dividing the multiplier from the previous year by the sum of inflation plus one.

$$Multiplier_t = \frac{Multiplier_{t-1}}{inflation + 1}$$

Values for inflation were taken from http://liberta.co.za/blog/cpi-inflation-rate-in-south-africa-current-and-historical/ which gets its information from Stats South Africa. The multiplier from 2005 in the previous study was used as the starting point and updated until 2012 using the inflation data.

4.4.3. Statistical Analyses

Descriptive statistics were used to quantitatively summarise the information about the data under study, trends and any other observations made. After establishment of positive relationships, further statistical methods were applied to determine the strength of the relationships between the input and output variables.

4.4.3.1. Trend Analyses

Trend analyses of income streams were plotted for the organisation in 1995 Rand value (Figure 1) and for the individual units, also in 1995 Rand value in Figure 2, while Figure 3 shows the various income streams values expressed as a percentage of total income.

4.4.3.2. Use of Discretionary Grant

The amounts or proportion of parliamentary grant invested in the various Frascati categories of research (A (Explorative), B and C (Exploitative) – see Table 3) were recorded by each unit in their unit annual performance reports, and the records were accessed from the Finance Department repository. For the purposes of this study, Frascati Type A research, which focuses on uncovering new knowledge at a more fundamental level to in order to contribute to a scientific or technological platform (Table 3) is synonymous with March (1991)'s definition of exploration, which he described as concentrating on the search, discovery and development of new knowledge. This type of research is highly associated with the uncertainties of the expected results, and include long-term research project to develop new capabilities and product platforms (March, 1991). Frascati Type B work on the other hand, is categorised as explorative work, defined by March (1991) as the refinement, extension and intelligent use of already existing competences. These R&D activities are incremental and short-term and can be directly connected to the applicability of its expected results (Arranz & Arroyabe, 2007).

4.4.4. Data Analyses

4.4.4.1. Investment into different Frascati categories of research

To evaluate if units invest significantly differently in the Frascati categories of research, particularly the proportion that the different units invest in Type A research, Tukey's Honestly Significant Difference (HSD) tests were performed.

4.4.4.2. Tukey's Honestly Significant Difference (HSD) test

A Tukey's HSD test is suitable for testing the significance of unplanned pairwise comparisons (Ref), which is appropriate as the paired comparisons of unit investment into various Frascati categories, was not planned. When an analyses involves multiple significance tests, the chance of finding a "significant" difference just by chance increases. The Tukey's HSD test preserves "family-wise type I error," or, put in another way, ensures that the chance of finding a significant difference in any comparison (under a null model) is maintained at the alpha level of the test.

4.4.4.3. Triplot analyses

Tri-plot is a Microsoft® Excel spreadsheet for the preparation of triangular (ternary) and tri-variate data (Graham and Midgley 2000). Conventional triangular diagrams are used to represent trivariate data in which the three variables represent proportions of a whole. A triplot of the proportional investment into the different types of research by the different units was made. Multiple t-tests on the same data sets to compare between different groups were deemed inappropriate. Thus, an analysis of variance was also performed.

4.4.4.4. Analyses of variance

Analysis of variance, also known as ANOVA, is perhaps the most powerful statistical tool. ANOVA is a general method of analyzing data from designed experiments, whose objective is to compare two or more group means.

4.4.4.5. Relationships between input and output variables

Correlation analyses were performed to establish the relationships between several input (financial) and output variables. For this investigation the correlational research approach was utilised to establish the links between income streams and research outputs and outcomes. In this approach it is crucial to observe the extent to which a statistical correlation between characteristics of a sample is discovered (Williams, 2007), depending to some degree of how well those characteristics have been calculated (Leedy and Ormrod, 2001). Therefore, validity and reliability are important components that affect observed correlations; statistical tests are necessary to establish patterns for two variables (Creswell, 2002).

4.5. Assumptions

In this study, the following assumptions are made;

1. Grant received by a public research institution from government are discretionary, and can be invested in either capacity building or technology development
2. The data for this study can be derived from historical information
3. The classification of research into Frascati categories (Types A to E) is consistent between business units
4. The current patterns of investment of PG into Frascati categories is reflective of the patterns the units followed prior to the period when recording the investment split became mandatory.
5. Profitability of the business unit is the correct optimisation function
6. Number of publications and royalty income are useful proxy measures.
7. Sustainability can be measured by financial margins

Table 3: Definition of Frascati Categories of Research (Summarised from OECD Frascati Manual, 2002)

STAGE NAME	ESSENCE	DESCRIPTION	STAGE TYPE
Strategic Basic Research	RESEARCH: The taking of an orderly approach to uncover new knowledge, will contribute to the building of a scientific or technological platform. The knowledge will be at a more fundamental level of understanding than that developed during 'Experimental Development' and with less 'Application Focus'.	Experimental/theoretical work to acquire new knowledge aligned with national or organisational imperatives ('Type A') • Research studies that aim to generate new knowledge at a fundamental level of understanding (of new material systems, establishing new mathematical techniques etc.) but done so with at least a conceptual plan as to how the research outcomes could be applied • Time scales to apply the knowledge could be 10 to 15 years from now	**TYPE A**
Applied Research		Original investigation to acquire new knowledge- directed towards a specific aim/application ('Type A') • Research conducted to generate specific knowledge that will be applied in a definite area of application, could be called 'Directed Research'. • The research findings might find application in the short to medium term (5 to 10 years). • The research might be done in order to deepen knowledge of an area where you already have knowledge	**TYPE A**
Experimental Development: Concept Testing	EXPERIME.NTAL DEVELOPMENT: The development of a new entity, e.g. a product, process or service using existing knowledge but also involving the creation of new knowledge , such new knowledge being at a less fundamental level than that developed during the 'Research' only phase and with more 'Application Focus'. Strong flavour of 'Incremental innovation'.	Drawing on existing knowledge directed towards producing/improving new product and service development ('Type B') • Working with existing, but also creating new knowledge, technology or sub-systems to test the value of new application concepts, no formal 'prototype' of the concept/product/process is produced but the various building blocks/principles behind the concept are evaluated • This could involve a paper based feasibility study, computer modelling etc	**TYPE B**
Experimental Development: Prototyping		• The activities that lead to formal testing of a concept or production of a real world version of the knowledge in the application. Could be as simple as making a prototype of a physical product or process, testing a new software application, evaluating a client response to a new service etc. New knowledge is still generated but at a less fundamental level. • Could be a non-paper based feasibility study	**TYPE B**
Technology transfer & Commercialisation for private gain and for public good	TECHNOLOGY TRANSFER & INDUSTRIALISATION	Knowledge application leading to new enterprises, product lines, consultancy reports & feasibility studies ('Type C') • The activities that formally turn the prototype or knowledge set into something that can be used in an application, readying it for the market and/or technology transfer to market based entity. • Includes intellectual property licensing and other kinds of commercialisation activities	**TYPE C**
Non-routine knowledge-based Services	KNOWLEDGE BASED SERVICE (KBS): The repeated use of a knowledge based to produce a result, includes consulting, analytical services and product manufacturing	• Activities that are not considered to be routine, including specialised consulting,, testing and analytical services and product manufacturing where no other source of such service or product exists in our market. • Could be early life-cycle stages in the application of a service or low-volume manufacturing of specialised high-tech items.	**TYPE C**
Routine Knowledge-based Services			

4.5.1.1. Correlation analyses

Correlation analysis tests the strength of relationships between dependent (input) and independent (output) variables. McDaniel and Gates (2006) defined correlation as the testing of the extent to which adjustments in a single variable are associated with corresponding adjustments in another. Thus it is a determination of the relation between two or more variables. Values of correlation coefficients can range from -1.00 to +1.00. A perfect negative correlation is represented by a value of -1.00, while a perfect positive correlation is has a value of +1.00. Spearman's rank correlations were used to evaluate relationships between financial inputs (various income streams) and outputs. The Spearman correlation coefficient can be described as the Pearson correlation coefficient between the ranked variables. Spearman was chosen over a Pearson correlation analysis because the Pearson analysis is predicated on the assumption of normality of data. Because of the limited data set (8 units over a 7 year period), normality of data could not be assumed thus the Spearman correlation analyses was used. The correlation coefficient may be interpreted as follows (Table 3.0).

Table 4: The interpretation of correlation coefficient used in the Spearman's rank correlation test

Correlation Coefficient	Interpretation
-1.0 to -0.8	High
-0.8 to -0.6	Substantial
-0.6 to -0.4	Medium
-0.4 to -0.2	Low
-0.2 to 0.2	Very Low
0.2 to 0.4	Low
0.4 to 0.6	Medium
0.6 to 0.8	Substantial
0.8 to 1.0	High

The analyses were made for each of the CSIR's research and development operating units, and then on aggregated pooled data for all 8 units. A regression analyses could also have been carried out, but was not selected as the analytical method of choice because of limited data (less than 30 units).

5. Chapter 5

5.1. CSIR income stream trend analyses

The CSIR has three main income streams, parliamentary grant, contract and royalty income. Figure 1 shows a trend analysis of all CSIR income adjusted to 1995 Rand value. The trend shows that the CSIR's total income was growing steadily since its inception, but dropped sharply in early 1990s. There has been a gradual but slow upward trend in the middle nineties, and another marked decline in 2005. The discretionary or parliamentary grant was the key source of income for the CSIR in its formative years (1946-1956), but has generally declined as a proportion of total CSIR income, recently (2010) falling below a third of the CSIR total income, as contract income continues to increase as a proportion of total income for the CSIR.

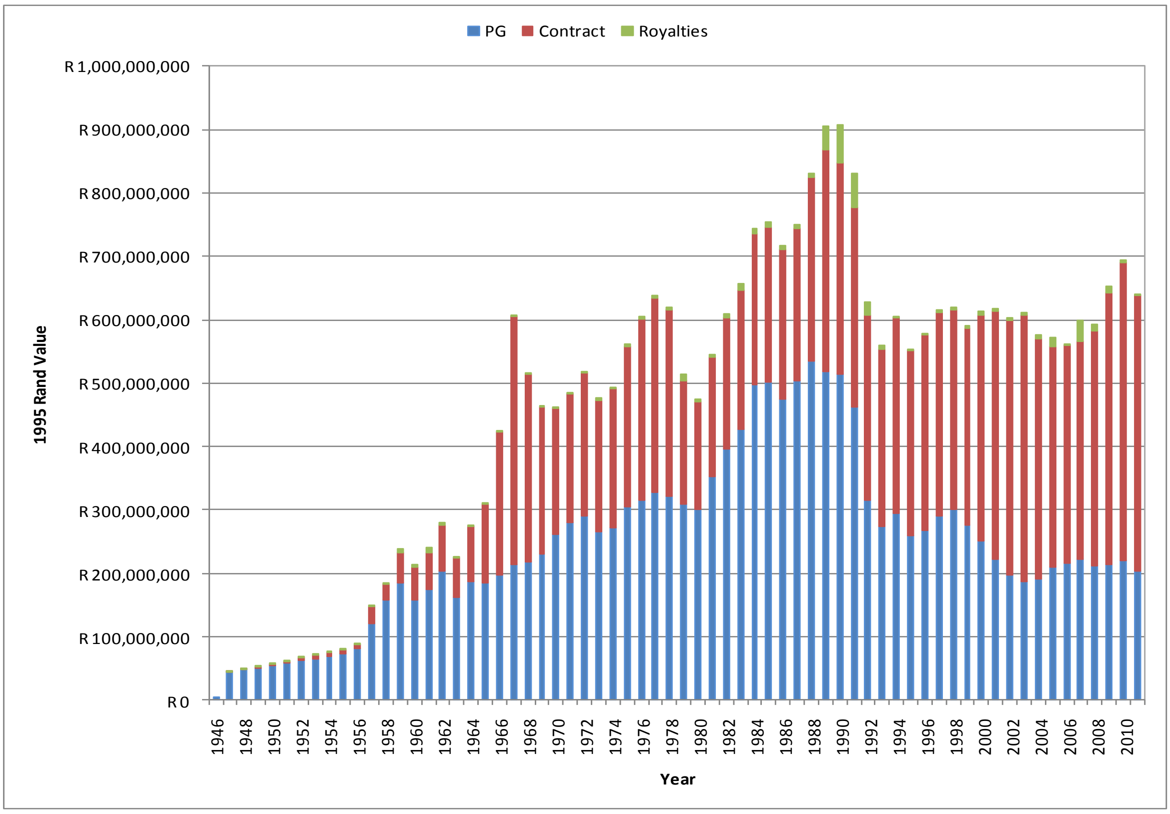


Figure 1: A trend analyses of CSIR income streams adjusted to 1995 Rand Value.

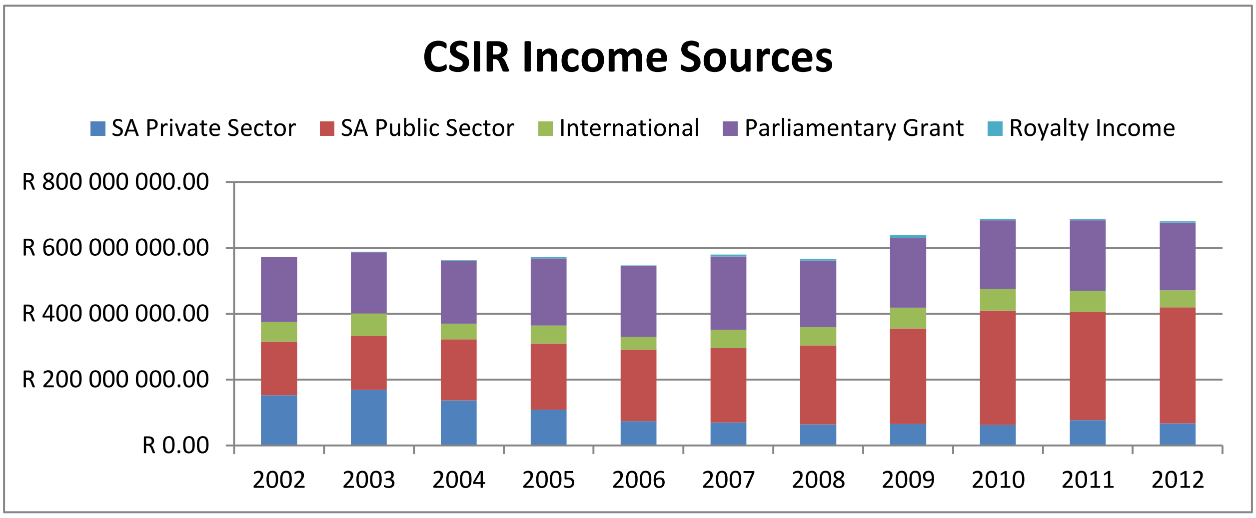


Figure 2: Breakdown of the CSIR's contact income by sources.

The CSIR's contract income was also broken down by source (Figure 2). Three main categories of contract income sources include South African public sector, which provides the bulk (41-75%), SA private sector and contracts from international public and private sectors. Since 2002, there was a general downward trend in CSIR's private sector income, and this trend appears to have stabilised since 2009. During the same period, public sector contract income has grown steadily, but international income remains more or less stable.

5.2. Individual unit trend analyses

Similar to the CSIR, the units have three income streams, parliamentary grant, contract and royalty income, with contract income comprising the bulk of the units' total revenues as shown in Figure 2.

5.2.1. Total income

The different units differ in the revenues (expressed in 1995 Rand values) that they generate as reflected by total income (Figure 3). DPSS is the largest unit by total income, peaking at R155 million in 2011 (Figure 3 a). The smallest unit is MDS (Figure 3d), which is also a very young unit, and it shows a gradual but upward trend in total income. Additionally, only DPSS, Meraka and MDS have (Figure 3a, b and d respectively) show obvious upward trends in income growth. BE, MSM, and NRE (Figure 3 c, e and g respectively) show a declining trend in total income in 1995 Rand value, and Biosciences is generally stagnant (Figure 3f) with a negative average annual profit.

5.2.2. Parliamentary Grant

For the highly profitable units, (i.e. units with average annual profit value above R5 million) units, Meraka and DPSS, (see Figure 4a and c), parliamentary grant contributes a small, percentage (10 and 11% respectively) of the total income of the business unit.

For the units that perform moderately well, (annual average profits of between R3 and 5 million), the Built Environment (BE, Figure 4e) and Material Science and Manufacturing (MSM, Figure 4(b), parliamentary grant constitutes on average 30% of the total income of the operating unit.

For the units that struggle to break even, the Biosciences (Figure 4e) and the Natural Resources and Environment (NRE, Figure 4f) units, parliamentary grant constitutes on average 36% of the total units income, and parliamentary grant proportion does not markedly decline over time (Figure 4 e, f, g).

Parliamentary grant is also used to establish new units, which effectively represent new capabilities for the organisation. When the new institutes are set up, they are supported predominantly by parliamentary grant, as is the case with the recent establishment of MDS and the NLC (see Figures 4d and 4h). The level of parliamentary grant as a proportion of total income declines as the unit gets older or more established, and the proportion declines steadily (see MDS and NLC, Figure 4d and 4h respectively).

5.2.3. Contract Income

For the highly profitable units, DPSS and Meraka, contract income is on average more than 85% of the unit's total income, and increasing. For the average and poorly performing units, contract income is closer to 60% or less and shows no obvious upward trend as is the case for NRE, Biosciences, BE and NLC (Figure 4e, f, g and h respectively). The new units MDS and NLC show a steadily increasing contract income as a proportion of total unit income. Overall for the CSIR aggregated data between 2005 and 2011, contract income is steadily rising above 70% of total income as the PG proportion declines.

5.2.4. Royalty Income

Most units receive some royalty income, and royalties range from 0-3% of individual unit's operating income for the period under study. For many of these units, royalties are not a significant proportion of total income, with the exception of DPSS where the average royalty income is about 3% of total income, and this unit receives royalties consistently. MDS and NLC, relatively young units, do not as yet earn royalty income.

CSIR, royalty income is not yet a significant part of the CSIR's income.

Relatively Sustainable | Relatively Not Sustainable

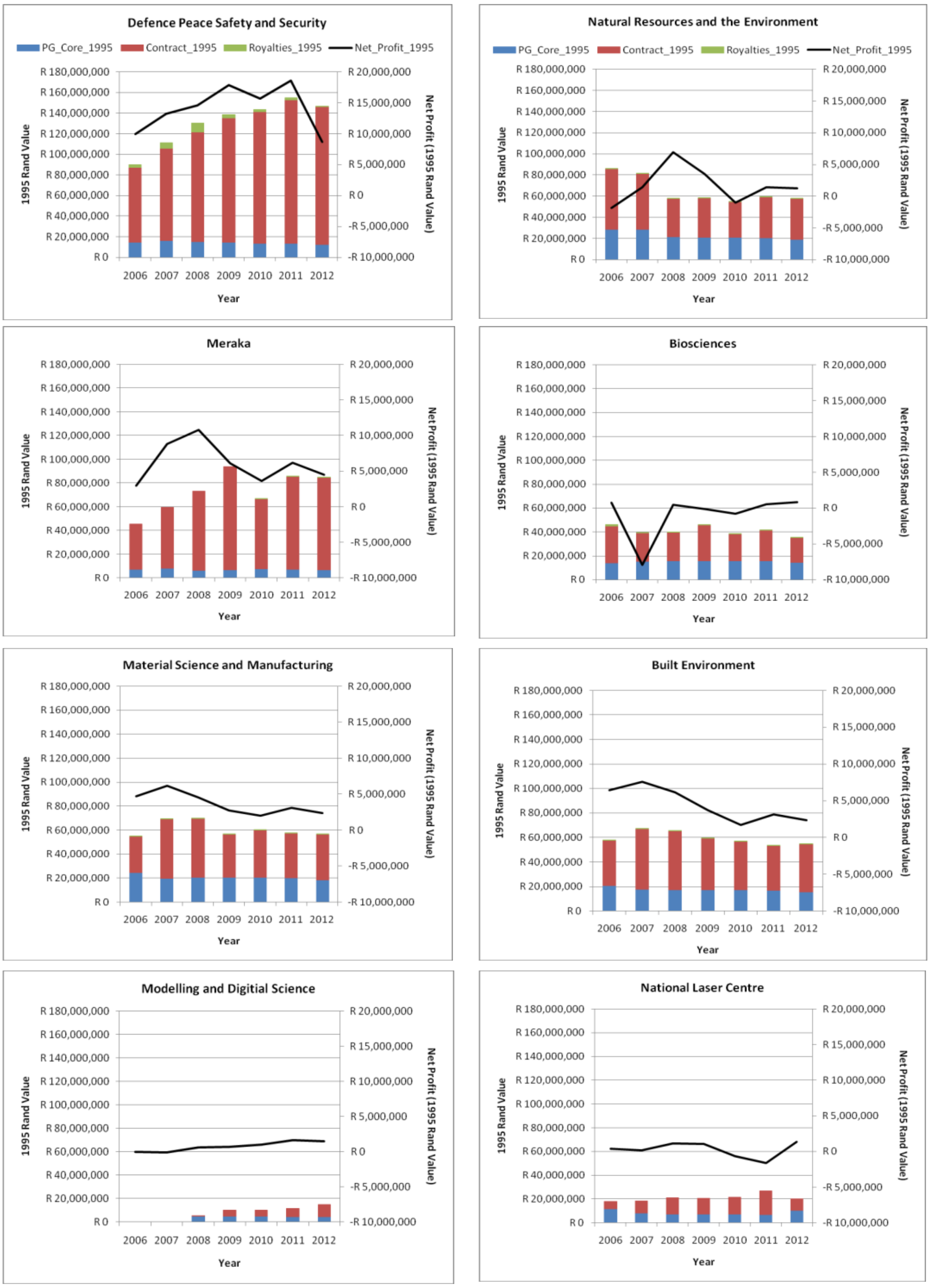


Figure (3): Plots of total unit income, separated into Royalties, Contract Income, and PG investment, per unit. The solid line represents the unit's Net Profit, adjusted to the 1995 Rand value

5.2.1. Annual Average Profits

Annual profits are a measure of a unit's ability to manage its operating costs, and are perhaps more importantly, a reflection of the unit's or enterprise's prudence in the manner in which it invests its discretionary resources in order to position itself to better earn other forms of income. The profitability of the individual units has already been discussed (Table 2).

For the period under study, DPSS, Meraka, BE and MSM showed average annual profits above R3 million. DPSS is the most profitable unit (Figure 3a), followed by Meraka (Figure 3b). A sharp decline is observed in DPSS's annual profit in 2012 is also observed. NRE has shown marked fluctuations in profits and a general downward trend (Figure 3e) while BE has declining profits, but no major losses. Bioscience registered a huge loss in 2007, and generally hovers below breakeven.

Pooled data indicates that the CSIR on average for the period under study made a profit of about R30 million (1995 rand value, Table 2).

5.3. Allocation of PG to exploratory and exploitive R and D activities

The CSIR invests parliamentary grant into Frascati categories A, B, and C, D, and E. PG allocation is allocated predominantly in the first three categories, A, B and C, as there were no significant amounts allocated to the rest of the categories, with nothing recorded for most units.

Figure 4 shows PG allocation into Frascati categories A, B and C by the CSIR's research and development units in 1995 Rand value. Table 4 also shows individual units' average annual percentage investment in various Frascati categories of research.

Relatively Sustainable

Relatively Not Sustainable

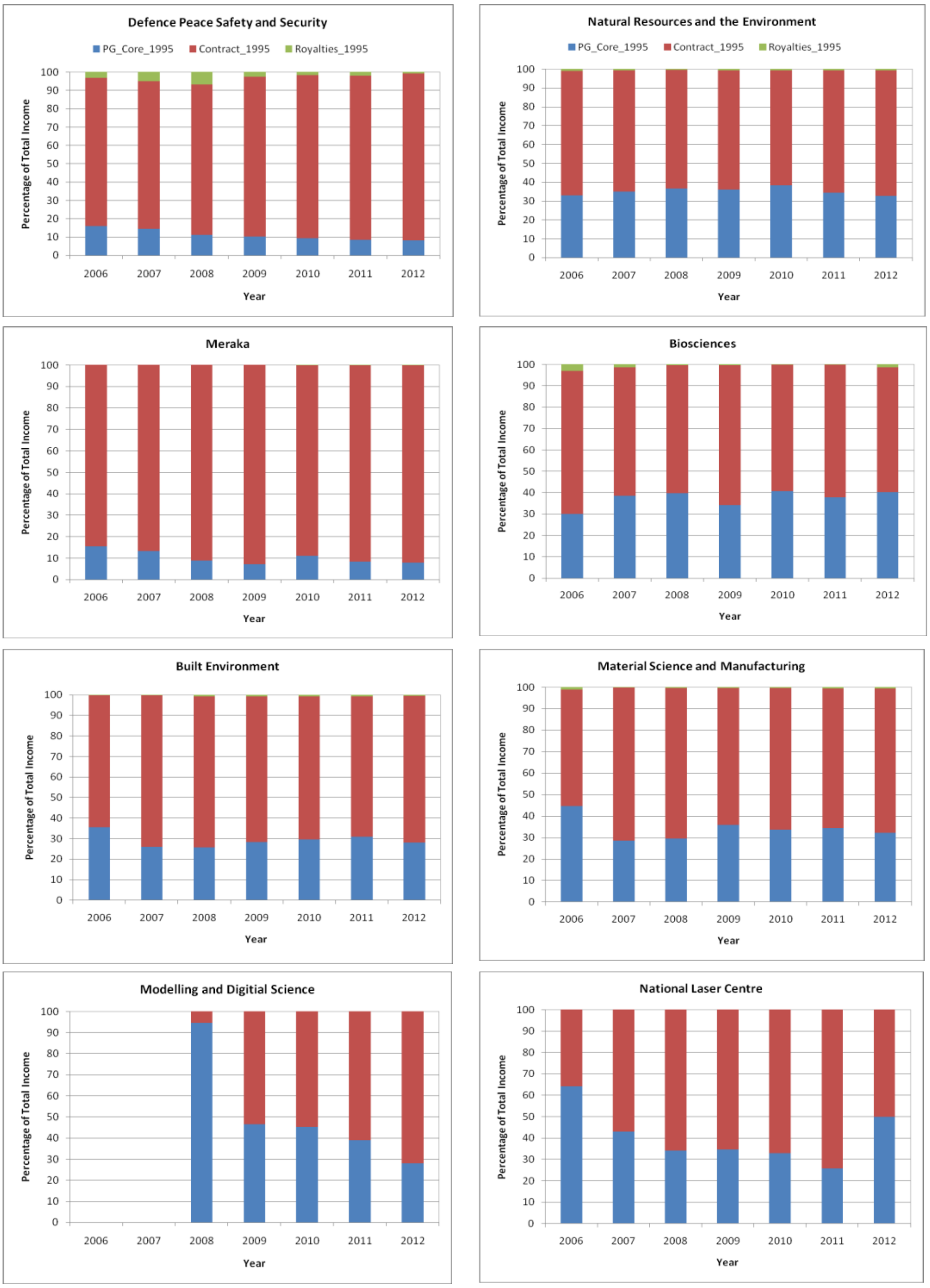


Figure (4): Plots of total unit income, separate into Royalties, Contract Income, and PG investment, per unit, expressed as a percentage of total income.

Table 4: Average annual percentage investment in various Frascati categories of research

Unit	Average Investment in Type A	Average Investment in Type B	Average Investment in Type C	Group
DPSS	53.29	36.49	10.2	Relatively Sustainable
Meraka	78.74	17.18	4.08	
BE	61.14	34.59	4.28	
MSM	64.94	27.15	7.9	
NRE	77.18	17.45	5.37	Relatively Not Sustainable
Bio	72.36	23.5	4.13	
MDS	60.02	39.94	0.16	
NLC	68.60	25.35	6.05	
CSIR R&D Units Pooled	**67.03**	**27.71**	**5.27**	**Sustainable**

Because of the role that the CSIR is expected to play in research translation, it was expected that it would invest substantially in Type B work. However, the enterprise invests about 67% of its parliamentary grant in Type A research.

DPSS, the most profitable unit, invests on average 53% of their PG on Type A work, while Meraka, also a profitable unit, invests, on average, 79% of its allocated discretionary grant allocation on Type A research for the period under study. Of the poorly performing units, NRE invest on average 77% of their parliamentary grant into type A research, followed by Biosciences, who invest 72% (see Figure 6, Table 4), above the organisational average investment into Type A work of 67%. Biosciences however, appears to be steadily increasing their investment in Type B research. The NLC, a relatively new center, invests on average, 69% of their parliamentary grant on Type A research, also above organisational average.

For the new unit, MDS, a significant proportion of PG goes into Type A research, also 60% on average, and this is below the organizational average of 67%. MDS, a new unit showing a robust upward trajectory of growth, Figure 2d, invests the largest proportion of the discretionary grant in Type B research. DPSS, the most successful unit, invested the next largest average proportion of PG in Type B work, on average 36% and 10% into Type C work (1% Type D).

Relatively Sustainable | Relatively Not Sustainable

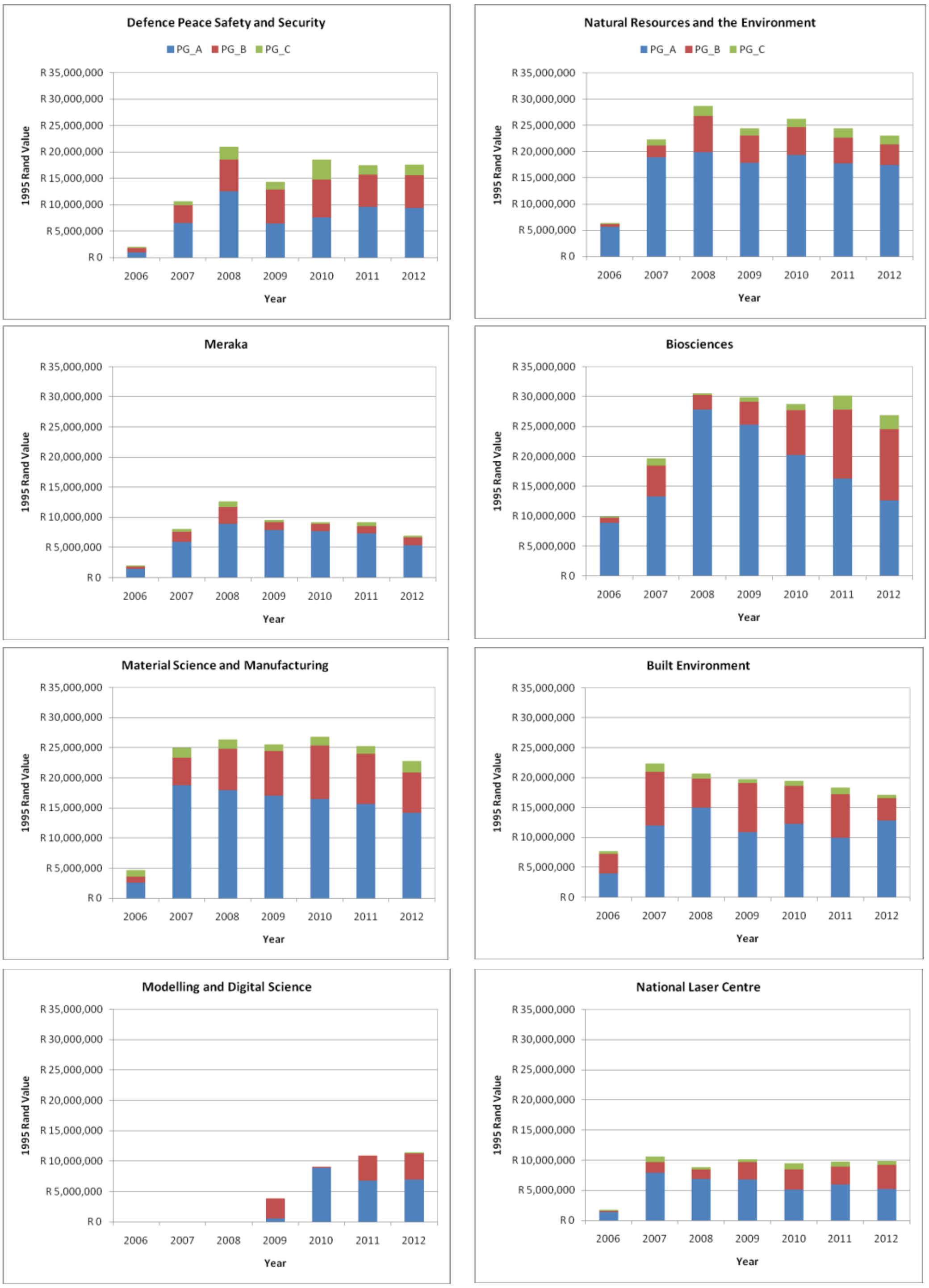


Figure 5: Bar graphs of Unit PG Investment, separated into Type A, B, and C research according to the Frascati Scale.

Relatively Sustainable | Relatively Not Sustainable

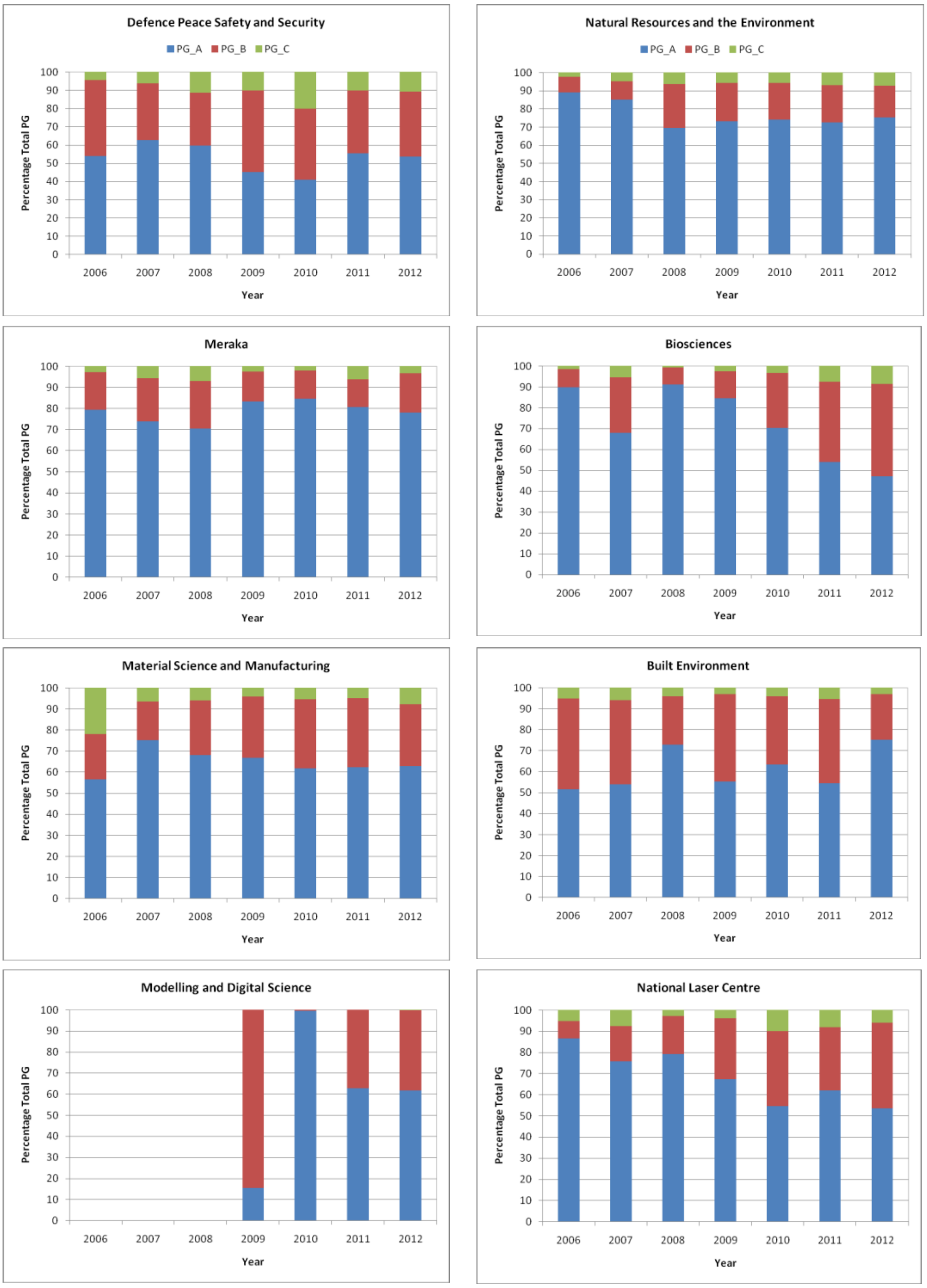


Figure (6): Bar graphs of Unit PG Investment, separated into Type A, B and C research according to the Frascati Scale, and plotted as a percentage of the Total PG income of the unit.

The units appear to invest differently in the Frascati categories of research. A triplot analyses was performed to further analyse differences in investment patterns by the units in the individual Frascati categories of research. Figure 7 below shows the triplot analyses on Frascati categories of research for different units. All of the points are in the bottom left hand corner which indicates that the proportion of investment into Type A research is more than 50% for all units. DPSS is the furthest away from the A corner and closest to B and C, indicating that this unit had the highest proportion of investment into Type B and C compared to any other unit.

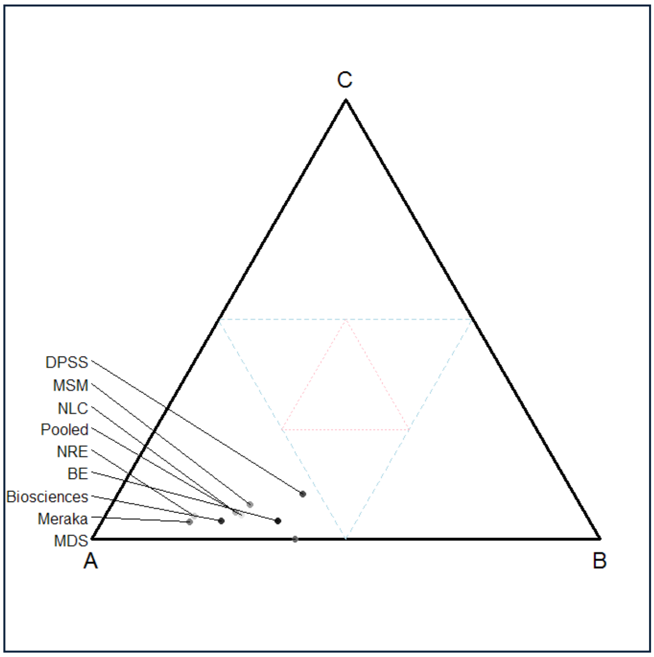


Figure 7: Triplot of proportion of investment into Type A, B and C research by the different units

Type A research is the category in which the units predominantly invested the bulk of their discretionary grant. Thus, an analyses of variance was also performed to compare the investment in this category of reasearch by the various units. The p-value for the analysis of variance test is 0.0114, which is significant at the 5% level. This shows that there is a significant difference in the way that units invest into type A research (Table 5).

Table 5: Analysis of variance test on proportion of investment into Type A research

	Degrees of freedom	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Unit	7	3679	2.998	2.998	0.0114 *
Residual	45	7890	175.3		

Additionally, a Tukey's Honestly Significant Difference analyses was used to compare interunit differences in investment into Type A, B and C categories of research, and the outcome of the analyses is shown in Table 6 below. Significant differences were obtained between the best performing units (Meraka and DPSS, p = 0.0167384, 5% significance level), whose patterns of investment are very different, as well as between NRE and DPSS (p = 0.0303176, 5% significance level).

Table 6: Tukey's Honestly Significant Difference Tests on differences in Allocation of the Discretionary Grant to Type A, B or C Frascati

Unit	difference	lower	upper	p-value
Biosciences-BE	11.229416	-11.261438	33.720269	0.7555604
DPSS-BE	-7.84016	-30.331013	14.650693	0.9517879
MDS-BE	-1.114785	-27.487648	25.258078	1
Meraka-BE	17.607395	-4.883458	40.098248	0.2269483
MSM-BE	3.810762	-18.680091	26.301615	0.9993605
NLC-BE	7.466032	-15.024822	29.956885	0.9627288
NRE-BE	16.040304	-6.450549	38.531158	0.3341269
DPSS-Biosciences	-19.069576	-41.560429	3.421277	0.1509751
MDS-Biosciences	-12.3442	-38.717063	14.028663	0.8099616
Meraka-Biosciences	6.37798	-16.112874	28.868833	0.984453
MSM-Biosciences	-7.418654	-29.909507	15.0722	0.9639761
NLC-Biosciences	-3.763384	-26.254237	18.727469	0.9994107
NRE-Biosciences	4.810889	-17.679964	27.301742	0.9971562
MDS-DPSS	6.725376	-19.647488	33.098239	0.9916575
Meraka-DPSS	**25.447555**	**2.956702**	**47.938408**	**0.0167384**
MSM-DPSS	11.650922	-10.839931	34.141775	0.7203343
NLC-DPSS	15.306192	-7.184661	37.797045	0.3928632
NRE-DPSS	**23.880465**	**1.389611**	**46.371318**	**0.0303176**
Meraka-MDS	18.72218	-7.650683	45.095043	0.3398191
MSM-MDS	4.925547	-21.447316	31.29841	0.9987981
NLC-MDS	8.580816	-17.792047	34.953679	0.9665331
NRE-MDS	17.155089	-9.217774	43.527952	0.4508686
MSM-Meraka	-13.796633	-36.287486	8.69422	0.5259606
NLC-Meraka	-10.141364	-32.632217	12.34949	0.8371412
NRE-Meraka	-1.567091	-24.057944	20.923762	0.9999984
NLC-MSM	3.65527	-18.835584	26.146123	0.9995131
NRE-MSM	12.229542	-10.261311	34.720396	0.6696102
NRE-NLC	8.574273	-13.91658	31.065126	0.924296

There is a significant difference in investment patterns between the two most profitable units units, Meraka and DPSS (p=0.017, at a 5% level of significance), as there is between DPSS and NRE, a struggling unit (p=0.03, at a 5% level of significance). Aggregate CSIR data shows that the organisation invests 67% of its discretionary grant on Type A research, 28% in Type B research and the balance in Type C work (Table 4, and see also Figure 9). At the level of the CSIR enterprise, a clear downward trajectory of of invetment in Type A work is visible, as the investment in type B and C research work increases.

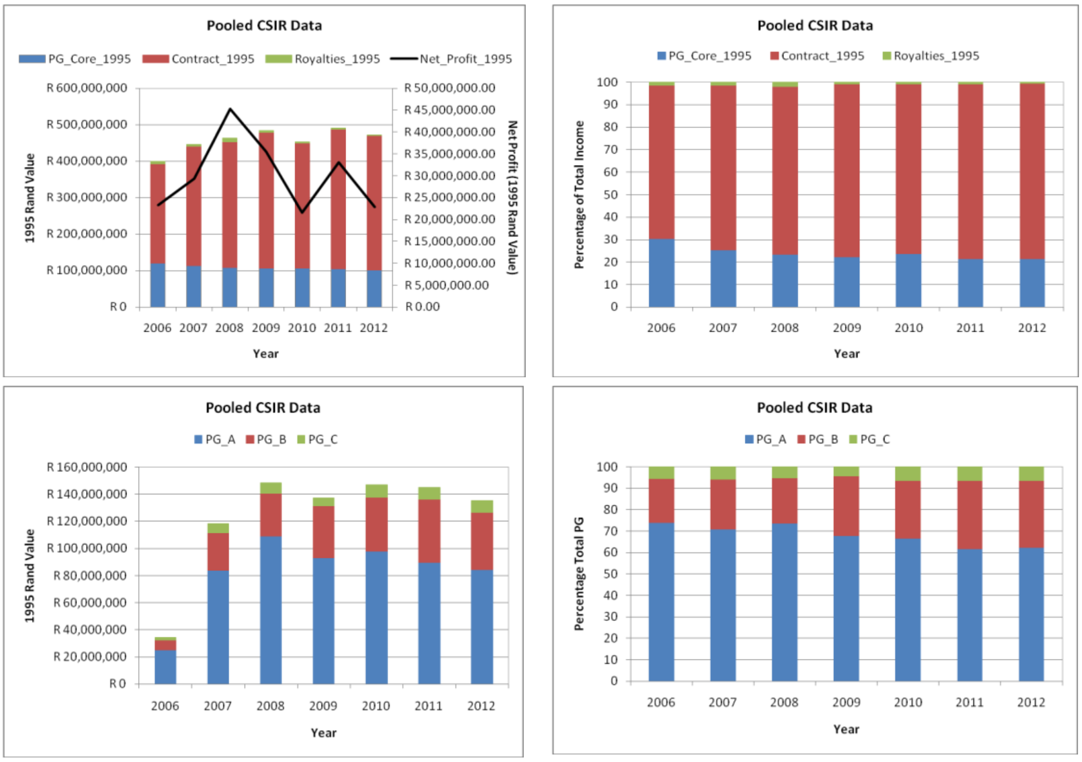
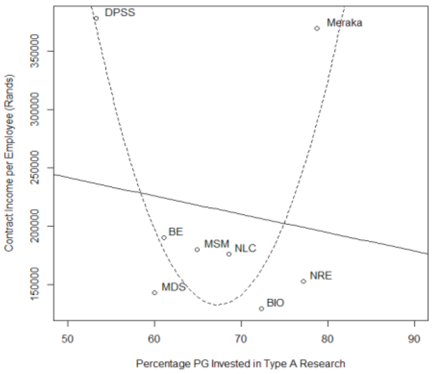


Figure (9): Plots of pooled unit income, separated into Royalties, Contract Income, and PG investment (top left), of Royalties, Contract Income, and PG investment, plotted as a percentage of total income (top right), of Unit PG Investment, separated into Type A, B and C research according to the Frascati Scale (bottom left), and of Unit PG Investment, separated into Type A, B and C research according to the Frascati Scale, and plotted as a percentage of the Total PG income of the unit (bottom right). The solid line represents the unit's Net Profit, adjusted to the 1995 Rand value

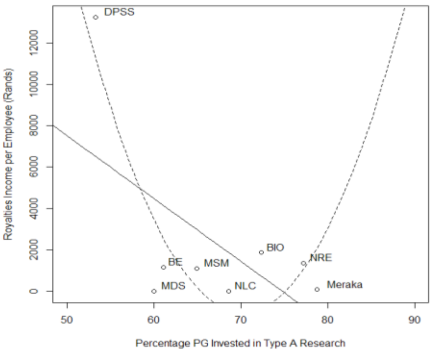
5.4. Effect of proportion of PG invested in Type A research on contract, royalty income and net profits

Figure 10 shows the effect of skewed investment of PG into Type A research on the ability of the units to earn contract and royalty income, as well as the sustainability of the unit as reflected by net profits. The income streams were normalised by the number of people in the unit. The ability to earn contract, royalty and net profit (Figure 9a, b and c respectively) declines as the proportion of PG invested in Type A research increases. Using regression analysis, the parabola represents the best fit (lower mean error in all cases). Similarly, Figure 10 also shows the effect of skewed investment of PG into Type A research on the ability of the units to earn contract and royalty income, as well as the sustainability of the unit as reflected by net profits. The more investment into Type B invested, the lower the ability to earn profits until a certain threshold is reached, and then the ability to earn contract income, royalties and net profits increases again.



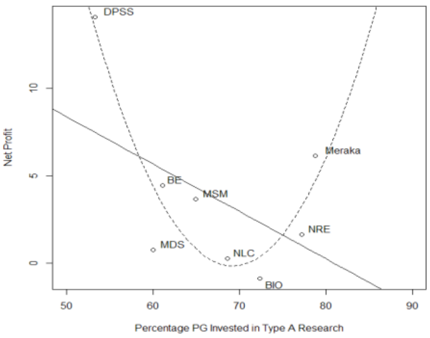
	Linear Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
Intercept	320246	310325	1.032	0.342
Percentage A	-1572	4594	-0.342	0.744
	Residual Standard Error = 107500; MAE = 78946			
	Parabola Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
a	5589779.5	1700863.3	3.286	0.0218
b × Percentage A	-162010.3	51516.3	-3.145	0.0255
c × Percentage A^2	1202.4	385.5	3.119	0.0263
	Residual Standard Error = 68620; MAE = 45884.92			

a) Contract Income per Employee versus Percentage PG Invested in Type A



	Linear Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
Intercept	22717.4	11087.6	2.049	0.0864
Percentage A	-303.7	164.2	-1.850	0.1137
	Residual Standard Error = 3842; MAE = 2807			
	Parabola Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
a	209883.15	61461.18	3.415	0.0189
b × Percentage A	-6002.25	1861.56	-3.224	0.0234
c × Percentage A^2	42.71	13.93	3.066	0.0279
	Residual Standard Error = 2480; MAE = 1706			

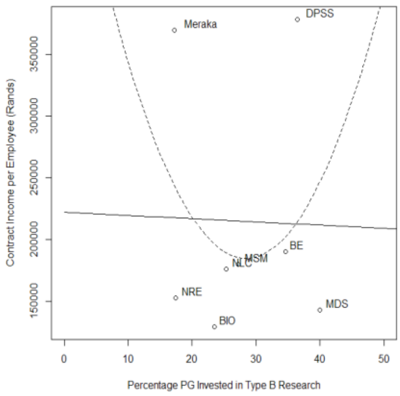
b) Royalty Income per Employee versus Percentage PG Invested in Type A



	Linear Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
Intercept	21.9426	12.9190	1.698	0.140
Percentage A	-0.2711	0.1913	-1.417	0.206
	Residual Standard Error = 4.476; MAE = 3.200			
	Parabola Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
a	256.7726	59.9192	4.285	0.00782
b × Percentage A	-7.4208	1.8149	-4.089	0.00946
c × Percentage A^2	0.0536	0.0136	3.946	0.01089
	Residual Standard Error = 2.417; MAE = 1.611			

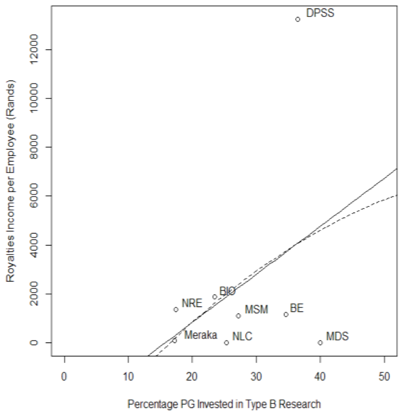
c) Net Profits per Employee versus Percentage PG Invested in Type A

Figure 9: Relationship between proportion of PG investment invested in Type A research and (a) contract income, (b) royalty income and (c) net profit.



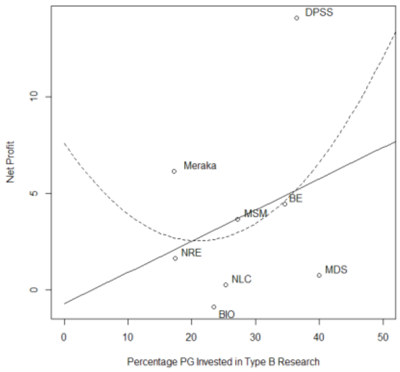
	Linear Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
Intercept	222055.3	138111.5	1.608	0.159
Percentage A	-260.3	4788.6	-0.054	0.958
	Residual Standard Error = 108500; MAE = 79631			
	Parabola Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
a	562406.7	600762.8	0.936	0.392
b × Percentage A	-26533.5	45263.2	-0.586	0.583
c × Percentage A^2	465.9	797.6	0.584	0.584
	Residual Standard Error = 115000; MAE = 72500			

a) Contract income per employee versus Percentage PG Invested in Type B



	Linear Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
Intercept	-3090.0	5672.2	-0.545	0.606
Percentage A	196.6	196.7	0.999	0.356
	Residual Standard Error = 4458; MAE = 2634			
	Parabola Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
a	-4676.394	25490.825	-0.183	0.862
b × Percentage A	319.024	1920.552	0.166	0.875
c × Percentage A^2	-2.172	33.844	-0.064	0.951
	Residual Standard Error = 4881; MAE = 2642			

b) Royalty income per employee versus Percentage PG Invested in Type B



	Linear Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
Intercept	-0.7153	6.2988	-0.114	0.913
Percentage A	0.1618	0.2184	0.741	0.487
	Residual Standard Error = 4.95; MAE = 3.25			
	Parabola Relationship			
	Estimate	Standard Error	*t*- value	*p*-value
a	7.602	28.057	0.271	0.797
b × Percentage A	-0.480	2.114	-0.227	0.829
c × Percentage A^2	0.0114	0.037	0.306	0.772
	Residual Standard Error = 5.373; MAE = 3.252			

c) Net profits per employee versus Percentage PG Invested in Type B

Figure 10: Relationship between proportion of PG investment invested in Type B research and (a) contract income, (b) royalty income and (c) net profit.

5.5. Correlation analyses

To determine the associations, if any, between the various proxies, correlation analysis was performed. The complete correlation tables are presented in Appendix 2. However, the data highlighted in this study is presented in Table &, 8 and 9 below.

5.5.1. Income streams and outputs

5.5.1.1. Contract income

This data refers to correlation analyses in Appendix 3. At the enterprise level, contract income is highly positively correlated with Type B investment (r^2 =0.89) and Type B normalised per employee (r^2 =0.85). There is moderate correlation between contract income and publications per employee (r^2 = 0.5). There is low positive correlation between contract income and net profits (r^2=0.39).

Additionally, at the enterprise level, there is high negative correlation between contract income and core PG and core PG normalised per employee (r^2 =-0.85 and r^2 =-0.92 respectively).

At unit level, in DPSS, contract income is highly correlated with new technology packages per employee (r^2 =0.71) and has medium correlation to net profit (r^2=0.43). In Meraka, contract income is highly correlated to publications (r^2=0.8), is moderately correlated to new PCT applications per employee (r^2=0.44) and is positively but weakly correlated to net profit (r^2=0.29). Contract income is negatively correlated to royalties (r^2=-0.5).

In MSM, there is a high positive correlation between contract income new invention disclosures per employee (r2 =-0.83) and new technology packages per employee (r2 0.75) and medium correlation with new PCT applications per employee (r2=0.64). No striking trends are observed for BE.

In Biosciences, contract income is substantially correlated to new start-up companies per employee (r2 =0.76), and is not correlated to net profit. There are not any noteworthy trends for this income stream in NRE.

In NLC, contract income has a high positive correlation to publications per employee (r^2=0.9) and patents granted per employee (r^2=0.71). In this unit, net profit is negatively correlated with net profit (r^2=0.57). MDS does not yet have data on the bulk of outputs analysed.

5.5.1.2. Core parliamentary grant

This data refers to correlation analyses in Appendix 3. At the level of the enterprise, core PG has substantial positive correlation with royalty income (r^2=0.75), and low positive correlation with new invention disclosures per employee (r^2=0.39), new technology packages per employee (r^2=0.290, new licence agreements per employee (r^2=0.39) and new start-up companies per employee (r^2=0.23), and new license agreements (r^2=0.60).

Notably, there is no correlation between core PG and net profit (r^2 =0.071) at the CSIR level.

At unit level, in DPSS, core PG is highly correlated to royalties (r^2=0.89) and royalties per employee (r^2=0.92), international patents granted per employee (r^2 =0.71) and new license agreements per employee (r^2=0.84). Core PG is moderately correlated with new invention disclosures per employee (r^2 =0.54). In this unit, core PG has a high moderate correlation to technology packages per employee (r^2 =-0.43). The core PG has virtually no correlation with net profit.

In Meraka, on the other hand, core PG has moderate correlation with royalty income earned (r^2=0.5) and high negative correlation with new PCT applications per employee (r^2= -0.89).

In Biosciences, core PG has substantial positive correlation to international patents granted per employee (r^2 =-0.6), new technology packages per employee (r^2=0.71) and publications (r^2 =0.66). For NRE, there are no striking positive correlations.

In NLC, core PG has high positive correlation with new invention disclosures per employee, and has negative correlation with publications (r^2 =-0.5).

5.5.1.3. Royalty income

This data refers to correlation analyses in Appendix 3. At the level of the enterprise, Royalty income is substantially positively correlated to new invention disclosures per employee (r^2=0.75), new PCT applications per employee (r^2 = 0.75), new PCT applications per employee (r^2 =0.64), new technology packages per employee (r^2=0.68) and new patents granted per employee (r^2=0.57), new license agreement per employee and new start-up companies per employee (r^2=0.41).

There is substantial correlation between royalty income and net profit (r^2 =0.68).

In DPSS, royalty income has substantial correlation to new license agreements per employee (r^2 =0.78), but is moderately correlated to new invention disclosures per employee (r^2 = 0.6). For Meraka, royalty income earned is perfectly correlated with new technology packages as they do not as yet earn income on licensed patents. Royalty income is perfectly negatively correlated with new start-up companies.

In Biosciences, there is medium correlation between new PCT applications per employee (r^2=0.54). Notably there is a high positive correlation between royalty income and new technology packages (r^2 =0.79), however, this correlation dissipates when the technology packages are normalised by number of employees (r^2 =-0.09).

In NLC and MDS, there are no royalties earned yet.

5.5.2. Correlation between Frascati category investments and outputs

5.5.2.1. Type A investment and outputs

For CSIR pooled data, the Rand Value of Type A invested is substantially correlated to new license agreements (r^2 =0.70), moderately correlated with publications (r^2= 0.57), new invention disclosures (r^2 = 0.58) and patents. Type A investment in Rand Value is weakly correlated to contract income (r^2= 0.43) and net profit (r^2= 0.36) , refer to Table 7a.

For unit data, there are no discernible general correlation trends that are distinguishable between the sustainable and the relatively not sustainable units. Rand value investment in Type A research is positively correlated with publications per employee in DPSS (r^2= 0.77) and Biosciences (r^2= 0.77), two units on opposite sides of the spectrum in terms of sustainability. Percentage investment in Type A research is strongly correlated to new technology packages in MSM (r^2=0.93), and moderately correlated to new technology packages in Meraka (r^2=0.56) and Biosciences (r^2= 0.53) (Table 7a). When the data is normalised per employee, there are no clear trends in correlations (Table 7b).

Table 7a: Correlations between investment of parliamentary grant (1995 Rand value) in Type C R and D activities and outputs in various units

	Publica-tions	New Technology Packages	New Invention disclosures	New PCT Applica-tions	Patents	Contract income	Royalty income	Net Profit
DPSS	0.77	0.29	-0.40	0.00	-0.00	0.57	0.00	0.21
Meraka	-0.81	0.56	0.31	0.87	N/A	0.50	0.50	0.57
MSM	-0.10	0.93	0.60	0.24	0.41	0.75	-1.00	0.29
MDS	N/A	N/A	N/A	N/A	N/A	0.41	N/A	0.20
Bio	0.77	0.53	0.43	0.46	0.61	-0.14	-0.64	-0.46
BE	-0.54	0.21	0.50	-0.71	N/A	0.54	0.00	-0.29
NRE	-0.20	-0.05	0.67	0.00	0.16	-0.71	-0.79	0.54
NLC	-0.80	0.29	0.29	-0.60	-0.40	0.21	NA	0.11
CSIR Pool	**0.57**	**0.55**	**0.57**	**0.45**	**0.54**	**0.43**	**0.04**	**0.36**

Table 7b: Correlations between percentage of parliamentary grant invested in Type A investment (exploratory) and outputs in various units normalised by the number of employees

	Publications/ person	New Technology Packages	New Invention disclosures/ person	New PCT applications / person	Patents/ person	Contract income/ person	Royalty income/ person
DPSS	-0.20	-0.09	0.26	0.46	0.26	-0.50	0.71
Meraka	-0.40	-0.70	-0.30	-0.40	N/A	0.11	0.50
MSM	-0.10	0.93	0.49	0.46	0.41	0.75	-0.80
MDS	N/A	N/A	N/A	N/A	N/A	-0.80	N/A
Bio	0.03	-0.20	-0.20	0.60	0.26	0.21	0.07
BE	-0.03	-0.30	0.90	-0.40	NA	0.61	0.29
NRE	-0.50	-0.30	0.30	-0.80	-0.70	0.46	0.71
NLC	-0.80	0.50	0.60	-0.45	-0.35	-0.18	N/A
CSIR Pooled	**-0.04**	**-0.09**	**-0.11**	**-0.14**	**-0.04**	**-0.04**	**-0.21**

5.5.2.2. Type B investment and outputs

For pooled CSIR data, there is a high positive correlation between investment in Type B research activities and royalty income (r^2= 0.82), and weak correlation with publications (r^2= 0.46), and a strong negative correlation (r^2= -0.75) with net profits (Table 8a). For normalised data (Table 8b), there are no obvious trends. However, the strong positive correlation between percentage of PG invested in Type B research and publications per employee in MSM (r^2= 0.94) and NLC (r^2= 0.90, Table 8a).

For pooled CSIR data on Rand value invested in Type C work, there are also no general trends between the income stream and the output and outcome proxies

Table 8a: Correlations between investment of parliamentary grant (1995 Rand value) in Type A R and D activities and outputs in various units

	Publica-tions	New Technology Package	New Invention disclosures	New PCT applications	Patents granted	Contract income	Royalty income	Net Profit
DPSS	0.60	0.29	-0.50	-0.80	0.07	0.54	0.64	0.32
Meraka	-0.40	0.87	0.67	0.58	N/A	0.29	-0.50	0.89
MSM	1.00	-0.06	0.37	0.32	0.46	0.07	-0.10	-0.70
MDS	N/A	N/A	N/A	N/A	N/A	0.80	N/A	0.40
Bio	0.37	-0.95	-0.26	-0.49	0.15	-0.64	-0.43	0.14
BE	-0.09	0.60	-0.70	0.00	N/A	0.50	0.21	
NRE	-0.20	0.15	-0.05	0.29	0.47	-0.93	-0.89	0.61
NLC	0.40	-0.30	-0.30	0.87	0.00	0.21	NA	0.11
CSIR Pooled	**0.46**	**-0.24**	**-0.21**	**0.07**	**0.04**	**0.82**	**-0.75**	**0.36**

Table 8b: Correlations between percentage of parliamentary grant invested in Type B investment (exploitative) and outputs in various units normalised by the number of employees

	Publica-tions	New Technology Package	New Invention disclosures/ Person	New PCT applications / person	Patents granted per person	Contract income/ person	Royalty income
DPSS	-0.31	-0.37	0.09	-0.14	-0.14	0.36	-0.43
Meraka	-0.40	1.00	0.50	0.67	N/A	-0.11	0.50
MSM	0.94	-0.29	0.20	0.03	0.41	-0.21	0.21
MDS	N/A	N/A	N/A	N/A	N/A	0.80	N/A
Bio	0.26	-0.37	-0.37	-0.60	-0.26	-0.21	-0.07
BE	0.09	0.50	-0.40	0.00	N/A	-0.61	-0.04
NRE	0.20	-0.10	-0.40	0.45	0.36	-0.61	-0.79
NLC	0.90	-0.70	-0.70	0.45	0.35	0.29	N/A
CSIR Pooled	**0.46**	**0.07**	**-0.14**	**0.00**	**0.04**	**0.75**	**-0.57**

In DPSS, Type B research is correlated with total staff (r^2=0.61) and publications (r^2=0.60) while in Meraka, Type B investment is positively correlated to new invention disclosures (r^2= 0.67), new PCT application (r^2= 0.58) and new technology packages (r^2= 0.87). In Biosciences, Type B investment is highly positively correlated with Type C (r^2=0.93), refer to Table 8b.

In DPSS, Type B is negatively correlated with new PCT applications (r^2=-0.84), and in Biosciences, it is negatively is negatively correlated with new license agreement (r^2=-0.97), new tech packs (r^2=0.95), new invention disclosures (r^2=-0.80), new PCT applications (r^2=-0.90).

5.5.2.3. Type C investment and outputs

Proportion of PG invested in Type C research activities only has medium correlation with publications (r^2 =0.5) as well as low positive correlation to contract (r^2 =0.39). Investments Type C have a medium correlation with royalty income (r^2 = -0.57) (see Table 9a).

There is high positive correlation between type C investment publications in Meraka, NRE and NLC (r^2 =0.8) in all these units. Technology packages are generally positively correlated with technology packages, with the exception of Biosciences, where there is a high negative correlation, and a general negative correlation with all outputs.

Table 9a: Correlations between investment of parliamentary grant (1995 Rand value) in Type C R and D and outputs in various units

	Publica-tions	New Technology Packages	New PCT applications/	New Invention disclosures	patents granted	Contract income	Royalty income	Net Profit
DPSS	**0.83**	**0.58**	-0.50	-0.60	0.07	**0.57**	-0.30	0.21
Meraka	-0.20	**0.36**	0.29	0.21	N/A	**0.43**	-1.00	**0.96**
MSM	-0.10	**0.58**	0.62	**0.77**	0.00	**0.75**	-0.20	0.00
MDS	N/A	N/A	N/A	N/A	N/A	**0.77**	N/A	0.26
BIO	-0.03	-0.74	-0.26	-0.26	-0.23	-0.43	-0.14	0.18
BE	-0.20	0.10	0.35	-0.70	N/A	0.43	0.04	0.21
NRE	**0.80**	**0.72**	**0.87**	-0.21	**0.95**	-0.61	-0.68	**0.54**
NLC	**0.80**	0.29	0.29	0.00	0.29	**0.64**	N/A	-0.60
CSIR Pooled	**0.50**	**-0.05**	**0.14**	**-0.18**		**0.39**	**-0.57**	**-0.36**

Table 9b: Correlations between percentage of parliamentary grant invested in Type C (exploitative) R and D and outputs in various units normalised by the number of employees

	Publica-tions	New Technology Packages	New PCT applications /person	New Invention disclosures	patents granted /person	Contract income	Royalty income
DPSS	**0.94**	**0.54**	-0.80	-0.5	-0.4	0.29	-0.32
Meraka	0.40	0.40	0.45	0.10	N/A	-0.14	-1.00
MSM	-0.77	-0.12	-0.06	-0.03	-0.64	0.14	0.32
MDS	N/A	N/A	N/A	N/A	N/A	0.77	N/A
Bio	0.26	-0.37	-0.6	-0.37	-0.26	-0.21	-0.07
BE	-0.03	0	0.35	-0.90	N/A	-0.39	-0.36
NRE	**0.70**	0.50	**0.89**	-0.50	**0.82**	0.29	-0.18
NLC	**0.60**	-0.20	0.11	-0.30	0.35	0.18	N/A
CSIR Pooled	**0.25**	**-0.56**	**-0.33**	**-0.57**	**0.04**	**0.11**	**0.60**

5.5.3. Other interesting associations observed

5.5.3.1. Age of unit

The age of the unit does not appear to play a role in the fortunes of a unit. Units that are older than DPSS are performing worse financially. However, it has a bearing on the ability of units to start generating inputs and outcomes.

5.5.4. Relating Findings to hypothesis

Hypothesis 1: The role of a public research institute is to translate basic research into value added innovations. To this end, the discretionary grant or parliamentary grant (PG) provided by government is a necessary initial investment to generate knowledge, in the form of publications, knowledge with added value such as patents, which are licenced to earn contracts and royalty income

There were no clear general trends of correlations between the outputs and the parliamentary grant, as both negative and positive relationships were observed. (H1a-H1c).

Hypothesis 2

Public research institutes are continuously seeking to create new knowledge in order to meet future needs even as they strive to exploit existing technologies to address current developmental challenges. The investment of the discretionary or parliamentary grant (PG) between capability creation (exploration) and capability exploitation is critical to the creation of a virtuous cycle of capability creation and utilisation reflected as enterprise sustainability measured as operational profits.

H1a: There is a negative correlation between increasing proportion of the parliamentary grant invested in Type A research and profitability

This hypothesis could not be categorically proven, as there was a negative relationship as expected, until a certain threshold was reached and then net income, royalties and profitability began to increase again.

H2b: There is a negative correlation between increasing proportion of the parliamentary grant invested in Type B research and profitability

Similarly, could also not be categorically proven, as there was a negative relationship as expected, until a certain threshold was reached and then net income, royalties and profitability began to increase again.

H2c: There is an optimal split between investment into exploration and exploitation for sustainability.

This hypothesis could not be proven as an optimal split could not be established; the relationship between the PG split and sustainability was dependent on several other factors such as guaranteed contact income.

Hypothesis 3

Generation of new knowledge is heralded as scientific and engineering publications. Publications should thus be a predominant output in environments where there is heavy investment in exploitive R and D activities (fundamental, Type A). As such, there should be a strong correlation between investments in Type A research and scientific and engineering publications.

Mixed trends were observed across the various units, so we cannot conclude that there are clear cut correlations.

Hypothesis 4

Addition of value to basic knowledge in the process of research translation results in patents, which are proxies for knowledge with application. Patents should thus be a predominant output in environments where there is heavy investment in exploitive R and D activities (translational, type B). As such, there should be a strong correlation between investment in type B research and patents, licence agreements and royalty incomes.

Mixed trends were observed across the various units, so we cannot conclude that there are clear cut correlations.

Hypothesis 5

Creating capabilities for the future requires spending financial and human resources for future returns, while exploiting the same capabilities earns such institutions income from royalties and contracted work from the private sector. These two processes are occurring simultaneously and constantly over time, and are possibly reinforcing each other. This is the basis of our fifth hypothesis, H5.

Some evidence was observed of the mutually reinforcing nature on these two concepts, but it was not a generic trend.

Chapter 6: Discussion

The role of a public research institution, or research council, in the South African system of innovation is primarily research translation, where universities are charged with basic research and training (Scholes et al, 2008). This study explores the link between various income streams that support research and development and the various outputs and outcomes. The study is particularly focused on the role of the discretionary or parliamentary grant, and how managers invest the grant into exploratory and exploitive research and development activities. Associations are also made between various income streams and outputs, as well as PG investment in basic (exploratory) research as measured by Frascati Type A and basic research related outputs, as well as PG investment in applied research as represented by PG invested in Frascati Type B and C, and the related outputs. The trends in CSIR income streams were tracked over time, since its inception in 1945 (Walwyn and Scholes, 2006). The split of the discretionary grant, however, was analysed for a period of the last 7 years when the CSIR and its entities started tracking the investment split.

5.6. Choice of case study

A case study approach was selected to understand the role of the discretionary grant in supporting the research and development activities of a public research institute, as well as to understand how the prudence in investment of the discretionary grant can lead to a sustainable model of operation for public research institutes. This is because while overall financial data for research institutes is readily available in annual reports, data on how the institutions allocate resources between exploratory and exploitive research institutions is not readily available. Thus the availability of such data for the CSIR represented a unique opportunity to understand the role of discretionary resource allocation in financial sustainability of a public research institute. The CSIR is the largest non-university multidisciplinary research organisation in South Africa, and its entities operate in R&D sectors for a total of 8 industrial sectors. Thus, the organisation and its entities, which make investment decisions independently, represented a microcosm of how R&D investments in different sector R&D could work, particularly in the context of an emerging economy. While the data obtained here is specific for the CSIR, the information can shed light on how these issues affect similar public research institutions in emerging economies.

5.7. Proxies of research inputs and outcomes

In selecting the proxies for research inputs, outputs and outcomes in this study, we assume an essentially linear innovation model in which basic research leads to applied research to inventions that can be transformed into innovations, which in turn lead to greater economic growth (Bush, 1945, Maclaurin, 1953). The scope of our study is, however, limited to assessment of basic research and its outputs, the translation of basic research to applied research and to inventions and licensure thereof. Empirically, this type of analyses focuses fundamentally on the link between research and development, and various proxies of research outputs such as patents in the first instance, followed by the link between patents and growth. The limitations of this approach include the fact that such a linear model does not account for tacit knowledge, and industrial differences in scientific research and so on (Rosenberg 1994, Nightingale, 1998).

However, it is a model that could allow the quantitative analyses that was required for the purpose of relating types of investments made by managers of business units with the outputs, and ultimately with sustainability.

5.8. Proxies of research and development outputs

Currently, most readily available proxies for research and development outputs and outcomes are derived from aggregate data, and though they are inadequate to fully reflect tacit knowledge and the idiosyncratic and path-dependent nature of innovation, they represent a form through which comparative analyses can be made quantitatively. Publications, new invention disclosures, patent applications, patents awarded, new licenses and revenue from IP, are useful outputs of investment in public research (Langford et al, 2006), and thus these were also included in the analyses. Outcome proxies include licensing and start-ups, and are also considered important as outcomes of prudent investment for the purposes of this study. Langford and co-workers (2006) also describe contracts as paths by which knowledge can be transferred across institutional boundaries, and as important measures of connectedness (particularly between R and D and the related sector industries), and they are quantified as contract revenues. Thus contract revenues were selected as an outcome proxy for prudent PG investment. These input and output measures are criticised as not reflecting the full view, but they remain valuable (Langford et al, 2006, Pavitt, 1998) and are thus used in this study.

5.9. Frascati categories of research

From 2002 - 2005, the CSIR went through a major institutional evaluation, with a subsequent strategic shift commencing in 2005, a process and strategy referred to as "CSIR: Beyond 60" (the CSIR had turned 60 years old in 2005). As part of the process, and starting in 2005, the CSIR started tracking and recording the investment of its discretionary grant investment in Frascati categories of R and D (see Table 2, OECD: Frascati Manual, 2002).

To recap, for the purposes of this study, exploration is research that focuses predominantly on the discovery of new knowledge and creation of new capabilities. The new knowledge may or may not be directed, and is synonymous with Type A research in Frascati classification of research. Exploitation on the other hand, refers to research that focuses predominantly on the application of knowledge and existing capabilities in the development of new products, processes or services, and is with Type B/C research in Frascati classification of research. The CSIR invests predominantly in Type A and B work, with no significant investment in Type D and E, thus Type D and E categories were not considered relevant for this study. This classification has facilitated assessment of the allocation of the parliamentary grant between exploration and exploitation in this study.

5.10. Income sources: funding for public research institutes

Public research institutes operate on a mixed income model, (Walwyn and Scholes, 2006), and they can be wholly funded by government grants, or they can be funded almost entirely by contract or project funding. The income streams which support research and development work include discretionary grant or parliamentary grant, contract income (money earned from public or private entities to execute specific types of work or research), as well as royalty income, from the licensing out of technologies.

5.10.1. Enterprise income sources and contribution of the parliamentary grant

The CSIR has always received discretionary grants from the South African government since its inception in 1945, and the proportion of its income that is made up of the parliamentary grant has been steadily declining over time.

The discretionary grant is given to public research institutions so that they can grow and maintain their capability (equipment, infrastructure and technology platforms) base, as well as to build new competencies. The CSIR was initiated by such a discretionary grant in 1945, and it did not start to earn other significant income at least for the first 15 years. This is also the case of new entities within the enterprise, MDS and NLC demonstrate the use of PG in this particular respect. When the entities were established, they were funded almost entirely by the discretionary grant or PG. As the units become established, they start to earn other sources of income. MDS is notably ramping up ability to earn contract income rather rapidly.

At the level of the enterprise (CSIR), there is a general decline in discretionary grant. The CSIR's contract income was, at the time of the study, was about 70% of the enterprise's total income stream (this includes funds from two other units that are involved in service work, as well as implementation), while royalties were about 1% of total income. The ability to earn contract income is an indicator that the organisation has established capability, it has heralded the presence of this capability through publications, patents and through networks with private and public sector entities, and is now recognised as a provider of research and development based solutions and services.

The predominant reason why the discretionary grant declines is usually the entity's ability to grow its other income streams, notably, contract income. In this case, the CSIR has been able to position itself and earn other income streams, importantly contract income and some sporadic royalty income. Thus the PG is a necessary initial investment required to develop and establish new competencies, as well as position the institution to earn other forms of income and ultimately be sustainable.

There are different views on the trend where contact income becomes a significant proportion of an organisation's funding. Some authors have argued that increasing contract income erodes the science base of an organisation (Lutjeharms and Thomson, 1993), and make public research and development expensive (Walwyn and Scholes, 2006). However, others perceive this a clear sign of the relevance that an entity is performing research and development work that is relevant to the system within which it operates, and because contract resources are competitive, generally the quality of the work proposed and executed is of a good enough quality as it is subject to peer review (Editorial: Nature 440, 581). In fiscally constrained environments such as South Africa and other emerging economies, government grants are not growing at the pace that is deemed necessary to significantly impact economic growth, and as such contract income is vital for sustainability of PRIs.

Data from this study shows that units of the CSIR that do not have significant contract income show a general downward decline in growth of revenue in real terms, and this trend threatens the long term sustainability of the operating unit and ultimately the enterprise.

5.10.2. Unit income sources and knowledge flow within their industrial sectors

The units, like the parent enterprise, also have a variety of income sources. However, the units vary in their ability to generate contract income. The data shows that for the individual operating units, the proportion of the discretionary grant as a proportion of the unit's total income varies significantly. For the units that thrive, such as DPSS and Meraka, the discretionary grant is a small proportion (10%) of the unit's income. The proportion becomes smaller still as the unit earns contract income and royalty income begins to flow. The ability to earn contract income is as a result of a certain market or industry sector appreciating and establishing that a unit or institution can meet their research and development needs, or contribute in some way to the innovation needs within their enterprises.

For units that are performing poorly, the discretionary grant generally tends to remain a large proportion (30% or more) of the unit's total income as the enterprise allocates more discretionary income to assist the units to meet their operational costs (akin to a bail out at the expense of the enterprise). Thus, when units do not earn other forms of contract income, they hamper the ability of the enterprise to grow and strengthen or create new capabilities with the PG. This is the case for units such as Biosciences, NRE and NLC. For the young units, the discretionary grant forms a significant component of a unit's income (MDS). As the units grow, and particularly if they thrive, then the discretionary grant proportion of total income declines steadily (MDS). However, when the units do not thrive, the proportion diminishes at a much slower pace (NLC). Clearly, the inability to earn other forms of income is a threat to the viability of the competencies represented in certain units, and ultimately the sustainability of the whole public research entity.

While the data in this study provides some evidence that the ability to earn significant amounts of other forms of income is vital, it does not shed light on how this impacts on scientific rigour as measured perhaps by the number of publications and the impact factors of the journals in which they are published, as well as patents and their citation.

5.10.3. The CSIR's role as a public research institution

The CSIR's income streams and their sources can be used as a proxy for assessing the role that the CSIR play in research and development in the local and global arena. It has already been observed that as the organisation or its units become older and more established, the proportion of the contract funding stream as a proportion of the total income has increased steadily. The bulk of this contract work at the level of the enterprise is from the local public sector, where the CSIR provides technology products and decision support tools to enable government to deliver services to society. In this instance, one can view the CSIR as a PRI that is fulfilling its public service/societal role.

The CSIR also receives contract income from the international public sector as well as local and international private sectors, a sign that it is evolving into a globally recognised public research institute (Bromfield and Barnard, 2010). It is noted in the literature that public research contributes significantly to industry by providing technologies for commercialisation (Link and Scott, 2005, Lerado and Mustar, 2004 and Nalin et al, 1997). The income earned from the private sector reflects that to a degree, the CSIR and its entities are playing the role of supplying technologies to industry.

The fact that the proportion of contract income is a small proportion of the total contract income may be suggestive of the fact that the CSIR needs to improve knowledge flow and connectivity between itself and the industry sectors in which it operates.

5.11. Investment of parliamentary grant in exploration versus exploitation

Critical to the effective execution of the PRI mandate, is the manner in which the PRI invests its discretionary grant, which is split between generating new knowledge (exploration), building new skills and technology platforms, and translating the knowledge and exploiting capability in order to generate patents, technology packages (exploitation). The argument that organisations need to balance their exploration and exploitation activities to achieve optimal performance is widely accepted in the literature (Berner and Tushman, 2003, Gupta et al, 2006 and Uotila et al, 2008).

For the purposes of this study, Frascati Type A research, which is focused on uncovering new knowledge, at a more fundamental level to in order to contribute to a scientific or technological platform (See Table 3) is synonymous with March (1991)'s definition of exploration, which he described as concentrating on the search, discovery and development of new knowledge, highly associated with the uncertainties of the expected results, and include long-term research project to develop new capabilities and product platforms (March, 1991). Frascati Type B work on the other hand, is categorised as explorative work, defined by March (1991) as the refinement, extension and intelligent use of already existing competences. These R&D activities are incremental and short-term and can be directly connected to the applicability of its expected results (Arranz & Arroyabe, 2007).

This study examines how the CSIR has invested its discretionary grant for the period 2005-2011. We examine this investment in the light of outputs that the organisation has generated, and the fact that the CSIR is a public research institution with a public service mandate. The study focuses on its operating units (OU) that are involved in research and development, and undertake investment decisions on investment semi-autonomously (unit managers have to present their strategies to the CSIR executive management committee, but the make the strategic decisions). The OUs vary in their age, some have existed since the inception of the organisation, although they have evolved over time (and are not obviously the same size nor shape). The CSIR has created units, merged and closed some over time as it tried to create new capabilities and to reconfigure new for efficiency gains. The units usually focus on specific capabilities in focal areas in which they specialise, although some slight overlap is common. The CSIR has also recently created new centres, such as the Modelling and Digital Sciences Unit (MDS), or received as part of its new core competencies the National Laser Centre (NLC), as other institutions are merged or wound down by government in the national system of innovation.

Aggregated CSIR data shows that at the enterprise level, the CSIR is investing its discretionary grant resources into both exploration and exploitation, although it is leaning heavily towards exploration, investing 67% of its discretionary resources towards exploratory work. March (1991) proposes that firms that overemphasize exploration, risk spending scarce resources with very little returns. Conversely firms that overemphasize exploitation reduce learning of new skills and might become bogged down in out-dated practices, knowledge and resources possibly depressing their long term performance (March 1991, Uotila, 2008). Balance is thus required between exploration (incremental change) and exploitation (radical change) as balance is at the heart of organizational adaptation (Gavetti and Levinthal, 2000). This need for dual organizational capabilities arises, in the case of publicly funded research institutions, in the face of social obligation and self-interest in the form of long term sustainability.

Gupta et al, (2006), also note that the balance with which an organisation can pursue both exploration and exploitation depends, to a significant extent, on whether the organisation perceives these two concepts as competing or as complementary. It would also be prudent to also consider the role that the institution ought to be playing in the system of innovation, particularly if it has a public mandate. The manner in which the CSIR perceives the concept of balance appears to be that these activities are orthogonal and complementary, pursuing both at the same time. The degree to which the CSIR pursues one or the other varies in it various entities. By mandate, the CSIR should be focusing more on research translation (Scholes et al, 2008), thus one would expect that it would invest more of the discretionary grant towards exploratory work. However, the relatively strong external income streams, while they are likely to be prescriptive in the work to be done, could also generate related exploitative activities that could be legitimately supported by the contract income, allowing the CSIR to invest more of its parliamentary grant substantively in type A work. This view is supported by Powell et al, (1996), who point out that often, organisations have access to not just their own resources, but other resources that in the environment. These may be accessed through collaborations and partnerships, which are key parts of contract work.

The connectivity between players in an innovation system is also key to how well each institution can pursue its mandatory role, and to effectively access additional resources. In young or immature innovation system, an entity may be forced to pursue activities further upstream in order to have access to enough proprietary novel work to keep it sustainable. In immature innovation systems such as the one in South Africa, basic knowledge that is generated in universities does not flow smoothly to science councils that are supposed to do the translation (see Figure 9), before industry and other public sector players translate the technologies into innovations that have an impact on society. Thus one finds that PRIs like the CSIR still need to do a lot of basic work as reflected by the subsequent investment in Type A work across the enterprise.

The concept of ambidexterity versus punctuated equilibrium refers to the synchronous pursuit of both exploration and exploitation, but in this case an organisation uses various units to specialise in one or the other. However, data from this study on the manner in which the CSIR is organised, and the parliamentary grant investment data show that the CSIR's operating units play in both exploration and exploitation. Thus the perception of these concepts is important at the individual unit level than at the level of the entity.

As such, the units interpret how this balance should be achieved quite differently. The data in this study shows that the units invest their discretionary grant significantly differently. DPSS, as an old, established and successful unit, appears to have an optimal investment profile. The unit is the one with the least skew towards Type A investment, and it also the second largest average investment into Type B and C research. This could be the basis of its profitability. Empirical tests of how the exploration and exploitation activities relate to performance have frequently taken modelled exploration and exploitation as orthogonal activities that positively interact (He and Wong, 2004, Jansen, Van den Bosch and Volberda, 2006, Labatkin et al, 2006), resulting in virtuous and positive feedback between exploration and exploitation. Units such as DPSS appear to have attained such equilibrium.

MDS, a young unit, has the largest proportion of the discretionary in type B work, and its notably ramping up its ability to earn contract income rapidly. In this unit, as at the level of the CSIR, there is a strong correlation between the parliamentary grant in Rand value invested in Type B research and contract income earned and with net profit. These two units, Meraka and DPSS, clearly perceive exploration and exploitation as complementary activities.

The case of Meraka is different from that of DPSS. It is also highly profitable entity. This unit works in ICT, and it invests heavily in Type A research work. This is possibly because of the nature of the work, where they predominantly strive to write new code and establish new algorithms which may end up with a variety of applications. An analysis of this unit's income shows that the unit receives large sums of money annually from the DST to install ICT support network for South African universities, and to run the Centre for High Performance Computing. Thus the money comes in to support the bulk of the unit's operations, hence the very low profit margins compared to a unit such as the DPSS. This unit illustrates that when a unit has a strong contract income stream, it can afford to invest heavily into exploratory work to create a strong IP base for the future. The unit can then, in future, shift its resources towards exploitation, a concept that depicts punctuated equilibrium (Gupta et al, 2006), temporarily cycling through periods of exploration and exploitation. The model of Meraka is consistent with literature (Gupta et al, 2006, Rangan, 2005), which points out that ICT is a space in which obsolescence of technologies is very high, thus it is important that organisations working in this space should invest heavily in exploration.

The units that struggle such as Biosciences and NRE, have historically invested heavily in type A work, and thus struggle to be sustainable because they possibly invest in exploration and not exploitation (March 1991, Uotila, 2008). Data is this study clearly highlights the negative correlation between the investing large proportions of the discretionary grant into either exploration or exploitation (Figure 8), emphasising the need for balance, or a clear strategy that shifts investment allocation from emphasizing one to the other over time.

March, (1996, 2006), proposed that because of the high risk nature of exploratory work, exploration could lead to a “failure trap”, where initial failure prompts further exploration, resulting in a vicious cycle of failure, and this could be a potential explanation for the poor sustainability of older units that have traditionally invested heavily in exploration such as NRE and Biosciences. Exploitation, on the other hand, often leads to early success, which in turn reinforces further exploitation along the same trajectory resulting in a virtuous circle of success. In this study, MDS is a classic example of this phenomenon. However, this view has to be tempered with caution, as clearly overemphasis of exploitation in the context can threaten sustainability.

Empirical tests of how the exploration and exploitation activities relate to performance have frequently taken modelled exploration and exploitation as orthogonal activities that positively interact (He and Wong, 2004, Jansen, Van den Bosch and Volberda, 2006, Labatkin et al, 2006). Units such as DPSS appear to have attained such equilibrium. It is noted that this unit is one of the oldest in the organisation.

The variation in how the successful units perceive the concept of balance suggest that several factors influence the decisions on investment, notably the industry a unit operates in, its connectedness to the players within and the industry’s absorptive capacity. (Conclusion)

5.12. Relating proxies of inputs and outputs

5.12.1. Investment into exploratory activities

In the linear and other models of innovation, the various income streams that are used to fund research and development are considered input proxies, while patents, licences and royalty incomes are considered output proxies. The study also examined how the investment in the different categories of research, have been accompanied by the types of outputs that are normally associated with investment types. Type A or basic research is associated with the generation of knowledge, which is generally scientific publications.

Generally, using aggregate CSIR data, type A research has a medium positive correlation with new invention disclosures, new PCT applications and publications (on average r^2=0.5), which is to be expected as these are typical Type A outputs. An explanation for this could be that there is not as yet a clear demarcation of what is classified as applied research work that is classified as Type A and that which is classified as type B, and that possibly the managers make different judgements in this aspect. Industry sector differences could also account for these differences. Additionally, exploratory work also yields new knowledge that can be published, distorting the view of what ought to be the typical outputs of which stage of research. However, when the data is broken down to the individual unit level, there is a general negative relationship.

5.12.2. Investment in exploitative activities

Generally, there were no strong trends observed on the correlations between investment in specific categories of research and the output and outcome proxies both at the level of the enterprise and the level of the units, with mixed positive and negative correlations between input, output and outcome variables. Given the challenge of establishing definitive cut-offs between the different categories of research, and the fact that exploitative activities funded by the discretionary grant as well as external income, it is not surprising that it was not possible to associate specific inputs with outputs, and to detect definitive correlations. .

5.12.3. Connectedness and maturity of the innovation system

The CSIR is an entity that is earning the bulk of its income, about 70%, as contract income. This can be viewed as a reflection of its effectiveness as a connector within the service and the more technical industrial clusters in which it operates. Contract work is predominantly applied or Type B work entails the use of knowhow existing internally and externally to perform work for external entities. This is also the reason for the positive correlation between contract income and Type B research (r^2= 0.82). Contract work also results in new (applied knowledge), notably registered as process patents or new gadgets, hence the positive correlation between contract income and scientific publications, new invention disclosures, new PCT applications and international patents granted.

Dissection of the contract income stream shows that the CSIR earns contract income predominantly from government departments, and a very small amount from the private sector. When we relate this to the entities dual mandate of fostering industrial research and improving the quality of life of people of the republic, it could be interpreted that the organisation is fulfilling its public service role very well, but is not as well connected with the relevant industry as it could be. Because the need to support government departs and state owned enterprises is going to remain substantial for the foreseeable future, this in itself is not detrimental to the entity's long term sustainability. But if the engagement with industry remains low, it may mean that the entity is not adequately supporting existing industries, or creating new ones as it ought to be.

5.12.4. Analysis of the internal businesses

The more connected units perform very well in terms of the three measures of connectedness. The DPSS unit is the most successful of the CSIR unit in terms of patents, contract and royalty income earned. The unit's success also translates to profitability. In units like DPSS, there is a strong correlation between contract income earned and publications, because of the predominant nature of contract income as the key component of income for the unit. Closer examination of the DPSS's sources income reveals that the DPSS is a strong connector; it is effectively positioned between research, the defence industries and the South African Department of Defence.

For a unit that is struggling such as Biosciences, which is not an effective connector, there is successful generation of outputs such as publications, possibly because of the unit's skewed investment of its parliamentary grant into Type A research. A closer examination of the client base for Bioscience shows that it is predominantly, for the period under study, funded by the Department of Science and Technology as well as its other funding instruments, up to 95% of total contract income. There is thus hardly any connection between this business and its related industry. However, the PG split for the past 2 years shows an increasing investment in Type B research, which could strengthen its translational work and improve its connectivity with industry. It is important to note here that the biotechnology industry in South Africa is rudimentary at best, and as such, there might not be enough absorptive capacity within the South African innovation space for a unit operating in this space to be sustainable.

The age of the unit does not appear to play a key role in the unit's ability to earn contract income, and to be able to get the correct investment profile. Prudence in management also plays a key role in success, MDS is only 4 years old but is showing attributes of success. The Built Environment is also quite an old and established institute, but is not as profitable as DPSS for example.

It is noted here that establishing the age of the individual units proved to be quite challenging. Many of the units do not bear the same income and configuration as they did when the disciplines that they work in were initiated. Thus the unit age was estimated on the basis of when the core discipline was established at the CSIR. This was not a challenge for the recently established units.

6. Chapter 7: Conclusions

6.1. Key findings and implications

The key question addressed by this study was the role of the discretionary grant in supporting the research and development activities of a public research institute, and how such an institute manages the exploration/exploitation tensions in resource allocation to achieve long term sustainability. The study focused on a single public research institute in South Africa, as well as its individual business units which operate generally independently of each other. However, some of the observations can have general application to public research institutes, especially when viewed in light of what authors who have worked in similar areas have reported.

In light of the evidence from this study, and the information available in the literature, the following conclusions are drawn;

- The discretionary grant plays a critical role as a funding stream for public research institutes, contributing to the effective execution of research and development activities of the entity. The discretionary grant is key in seeding new national competencies, and is a key initial investment in enabling the PRI to establish itself, generate outputs and outcomes that herald its competencies and thus position itself to earn other forms of income.
- The manner in which the investment is split between exploration and exploitation is critical to the long term sustainability of the enterprise. Skewing investment in either exploration or exploitation alone is detrimental to sustainability.
- The optimal split of the discretionary grant between exploration and exploitation is dependent on several factors, to include, the technology bases of the industries in which the entity operates and the connectivity and paths of knowledge flow in the innovation systems nationally and globally.
- Inability to earn other forms of income is in itself a threat to the long term sustainability, particularly in fiscally constrained environments that are typical of emerging economies. The ability to earn external income provides options for investment of the PG in building its capability base. Notable here is the fact that the absorptive capacity of the industry sector in the first place, the innovation system in which the entity operates and the connectedness of the entity within the system appear to have important influences on ability to earn other forms of income. In

such cases, strategic decisions have to be made on whether the sector remains strategic enough for the country in deciding on continued investment.

6.1. Limitations of the Study

There are a few challenges that place limitations on the broad applicability of the data and the findings from this study. The limitations lie in the data itself and the possible analysis that could be done with it.

The fact that data was collected over the past seven years only is a limitation, and, in future the study could be extended over a number of years to make the findings more robust. This is because there is often a lag period between investment of the discretionary grant and a return on that investment by way of outputs such as scientific publications, patents and contract income, and outcomes such as technology licence, spin out companies and royalty income. The period under study of seven years thus reflect the consequences of investment decisions made in prior years, and for younger units, the consequences of such decisions in the form of outputs and outcomes may take a long time yet to come to fruition. Thus one could argue that it is not possible to establish causality between prudence of current investment decision of the discretionary grant and PRI sustainability. However, the assumption here is that the units were probably investing their investments in this fashion prior to the time that they actually started recording the invention splits in 2005.

The number of units analysed was also limited, the CSIR has only 8 research and development units. Because of the limitations in the number of units under analyses, robust techniques to analyse relationships between input and output variables such as regression analyses could not be used.

Additionally, not all the units have generated the kind of outcomes that are being analysed in the study, although by mandate, they are expected to due to a variety of reasons. Notably some young units do not earn royalties, and neither have they licenced technologies.

The use of operating profits as a measure for sustainability could also be challenged, as the primary objective of public research institutes is not to make profits. On occasions where they are profitable, these resources are ploughed back into building and maintaining the entity’s capability.

The CSIR is a single public research institute which operates in a unique environment with first world/emerging market dichotomy. This places a limitation on the broad applicability of some of the observations and findings, although when viewed against the backdrop of current literature, this work is a valuable addition to the existing body of work, and could be particularly useful to PRIs in emerging economies.

The units also differ in age, and age places a limit on the validity of the comparisons between units. However, it shows how the PRI uses its discretionary grant to establish new competencies in the form of new research entities.

The fact that the different units operate in diverse industries of varying degrees of maturity within the country is a double edged sword for this study. Where the industry sector is rudimentary, this affects the connectedness of the unit, and its ability to find a market for its technologies and to earn external income. Where there is a mature industry, the unit can be readily connected. However, this could also be the strength of this study as rudimentary industry sectors are a hallmark of many developing economies, and thus the findings could be extended to PRIs in other developing economies.

6.2. Managerial implications of research findings

The results of this study show that there are several factors that managers should consider before making investment decisions regarding exploration and exploitation decisions. The study shows clearly that skewed investment in either category is detrimental to the future sustainability of the enterprise and its entities. The ability to earn other forms of income is an important consideration, as it provides additional options for supporting research and development activities. Thus, the chaotic choice on resource allocation is thus dependent on other available options, and there would be benefit in paying more attention to resource allocation.

6.3. Issues for future research

The study confirms a lot of what is already known in the existing literature, but it provides some new insights as well. Future studies could focus on exploring the effect of a PG partitioning over a much longer period. In this study, data on PG allocation in exploratory and exploitive activities has only been available for 7 years, yet it is known that the return on investment of discretionary grant can take years. Thus data over a longer period as well as analysis of the lag time between investment and outputs would be valuable.

The data from reinforces the importance of other forms of income in the sustainability of a public research entity. A concern about contract or project income eroding the science base or eroding the rigour with which science can be executed is raised in the literature. Future work could perhaps explore increased contract work impacts on the number and quality of research and development outputs of a public research institute.

Future work should also explore the relationships between the various units and their industry players, stakeholders and customers, as these factors also have an important influence on the fortunes of an entity.

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Appendix 1: Summary of CSIR overall data which shows the income received from Parliamentary Grant, Contract and Royalties. The Rand value has been adjusted to the 1995 Rand value using the same multipliers as Walwyn and Scholes (2006) and Scholes et al. (2008). The multipliers for 2009 to 2012 were calculated from the CPI inflation values for these years as reported by Stats South Africa.

Financial Year	Employees	Multiplier 1995	Parliamentary Grant	Contract	Royalties	Total (From all Income Sources)
1946	0	63	R 3,908,829.47	R 0.00	R 0.00	R 3,908,829.47
1947	0	58	R 43,491,967.80	R 455,938.10	R 291,601.75	R 44,239,507.65
1948	0	56	R 47,082,570.91	R 1,221,104.97	R 265,975.41	R 48,569,651.29
1949	0	53	R 50,673,174.03	R 1,986,271.84	R 240,349.08	R 52,899,794.94
1950	0	48	R 54,263,777.14	R 2,751,438.71	R 214,722.75	R 57,229,938.59
1951	470	46	R 57,854,380.26	R 3,516,605.57	R 189,096.41	R 61,560,082.24
1952	0	44	R 61,444,983.37	R 4,281,772.44	R 163,470.08	R 65,890,225.89
1953	0	41	R 65,035,586.49	R 5,046,939.31	R 137,843.74	R 70,220,369.54
1954	0	40	R 68,626,189.60	R 5,812,106.18	R 112,217.41	R 74,550,513.19
1955	1,000	41	R 72,216,792.72	R 6,577,273.05	R 86,591.07	R 78,880,656.84
1956	1,200	40	R 80,364,384.32	R 7,622,429.13	R 128,188.04	R 88,115,001.49
1957	1,300	39	R 121,198,661.69	R 25,951,998.15	R 315,903.72	R 147,466,563.57
1958	1,514	39	R 156,772,692.64	R 26,166,099.27	R 649,979.89	R 183,588,771.80
1959	1,786	39	R 184,801,500.80	R 48,344,357.71	R 5,142,294.08	R 238,288,152.59
1960	1,943	38	R 156,909,145.15	R 52,085,294.43	R 4,352,700.04	R 213,347,139.62
1961	2,033	37	R 174,645,956.93	R 58,059,274.01	R 8,133,331.93	R 240,838,562.87
1962	2,040	37	R 203,685,754.56	R 71,683,614.83	R 5,125,390.89	R 280,494,760.27
1963	2,050	36	R 161,674,322.37	R 62,367,651.23	R 2,800,354.95	R 226,842,328.55
1964	2,099	35	R 187,044,969.96	R 86,098,550.76	R 863,929.78	R 274,007,450.50
1965	2,440	34	R 184,856,311.81	R 123,997,603.25	R 1,257,405.16	R 310,111,320.23
1966	2,659	32	R 197,340,736.36	R 224,742,663.23	R 934,008.92	R 423,017,408.51
1967	2,865	31	R 213,635,496.13	R 391,013,894.01	R 2,898,977.46	R 607,548,367.61
1968	2,938	30	R 218,311,473.90	R 294,946,439.44	R 966,520.62	R 514,224,433.97
1969	3,160	28	R 229,948,403.23	R 231,630,117.29	R 1,324,666.09	R 462,903,186.61
1970	3,185	27	R 261,497,091.57	R 198,951,663.19	R 2,214,294.27	R 462,663,049.03
1971	3,288	26	R 279,091,078.26	R 203,616,893.17	R 1,868,710.18	R 484,576,681.60
1972	3,421	23	R 290,427,302.77	R 225,262,378.44	R 1,672,409.40	R 517,362,090.61
1973	3,516	19	R 266,100,528.92	R 206,658,295.86	R 4,339,302.79	R 477,098,127.56
1974	3,575	17	R 271,192,245.47	R 219,634,325.12	R 2,428,696.37	R 493,255,266.96
1975	3,633	15	R 305,537,485.94	R 252,979,669.13	R 3,157,042.17	R 561,674,197.23
1976	3,820	14	R 314,561,734.08	R 287,481,920.75	R 2,771,201.48	R 604,814,856.31
1977	4,084	12	R 328,329,797.36	R 306,300,663.90	R 3,848,048.19	R 638,478,509.45
1978	4,161	11	R 322,146,168.82	R 294,193,939.66	R 3,513,578.68	R 619,853,687.17
1979	3,949	10	R 309,191,086.95	R 195,201,493.23	R 8,985,771.55	R 513,378,351.74
1980	4,175	8	R 300,657,999.59	R 168,892,469.41	R 5,927,202.40	R 475,477,671.40
1981	4,252	7	R 352,912,604.85	R 187,903,616.47	R 5,217,716.83	R 546,033,938.15
1982	4,380	6	R 395,760,924.59	R 207,420,656.38	R 6,973,633.45	R 610,155,214.42
1983	4,622	5	R 428,076,105.49	R 219,099,047.66	R 9,069,076.27	R 656,244,229.42
1984	5,001	5	R 497,144,201.23	R 237,992,836.25	R 8,184,626.24	R 743,321,663.72
1985	4,898	4	R 502,326,805.89	R 243,855,438.37	R 7,876,784.85	R 754,059,029.11
1986	4,712	4	R 475,281,351.39	R 235,229,185.73	R 7,163,284.98	R 717,673,822.10
1987	4,763	3	R 503,263,574.67	R 240,351,708.08	R 7,047,701.70	R 750,662,984.46
1988	4,557	3	R 535,404,073.98	R 289,689,629.32	R 6,856,203.83	R 831,949,907.13
1989	4,438	2	R 517,420,734.02	R 351,847,973.30	R 37,157,586.14	R 906,426,293.46
1990	4,278	2	R 514,808,431.01	R 331,819,537.40	R 61,050,805.72	R 907,678,774.13
1991	3,819	2	R 462,009,900.98	R 315,852,670.58	R 53,128,557.71	R 830,991,129.27
1992	3,573	1.50	R 314,708,808.15	R 291,738,937.43	R 20,614,140.25	R 627,061,885.82
1993	3,211	1.34	R 274,496,118.74	R 278,944,337.50	R 6,328,255.94	R 559,768,712.18
1994	2,991	1.23	R 294,679,699.12	R 308,451,544.79	R 1,184,265.82	R 604,315,509.73

Financial Year	Employees	Multiplier 1995	Parliamentary Grant	Contract	Royalties	Total (From all Income Sources)
1995	3,047	1.11	R 259,817,678.57	R 291,480,570.88	R 2,809,604.24	R 554,107,853.69
1996	3,106	1.03	R 267,202,230.52	R 308,451,307.79	R 2,522,791.39	R 578,176,329.70
1997	3,043	0.95	R 289,891,987.76	R 321,709,261.51	R 2,929,145.76	R 614,530,395.03
1998	2,965	0.90	R 301,309,230.22	R 315,200,163.25	R 3,192,710.26	R 619,702,103.72
1999	2,860	0.85	R 276,028,388.99	R 311,410,033.20	R 3,499,236.89	R 590,937,659.09
2000	2,631	0.79	R 250,168,878.04	R 356,684,965.64	R 6,754,937.76	R 613,608,781.44
2001	2,555	0.73	R 221,107,692.34	R 392,329,192.68	R 4,956,901.48	R 618,393,786.50
2002	2,524	0.66	R 197,306,082.36	R 401,309,258.83	R 5,426,394.11	R 604,041,735.30
2003	2,452	0.63	R 185,773,406.04	R 421,036,039.02	R 3,703,784.54	R 610,513,229.60
2004	2,430	0.59	R 191,198,700.33	R 379,392,218.55	R 5,205,182.07	R 575,796,100.95
2005	2,379	0.57	R 208,653,723.53	R 347,992,963.31	R 15,198,992.91	R 571,845,679.75
2006	2,179	0.55	R 216,019,966.66	R 343,461,097.39	R 1,887,845.02	R 561,368,909.08
2007	2,207	0.52	R 221,081,317.07	R 343,755,201.76	R 33,382,259.67	R 598,218,778.50
2008	2,256	0.49	R 210,609,167.20	R 372,630,455.45	R 9,818,311.67	R 593,057,934.32
2009	2,363	0.45	R 212,679,109.37	R 430,467,360.46	R 9,501,591.94	R 652,648,061.76
2010	2,396	0.41	R 220,122,105.26	R 470,037,595.38	R 3,446,526.82	
2011	2,427	0.40	R 203,171,070.00	R 434,423,592.40	R 2,928,739.81	
2012		0.37				

Appendix 2: The summary of the income received from Parliamentary Grant, Contract and Royalties.
The Rand Value has been adjusted to the 1995 Rand Value.

Unit	Year	Contract Income	Percent Contract	Royalties Income	Percent Royalties	PG Core Income	Percent PG	Net Profit	Total
BE	2006	R 37,125,550.31	64.18	R 58,360.86	0.10	R 20,659,749.01	35.72	R 6,434,938.44	R 57,843,660.17
BE	2007	R 49,496,933.54	73.77	R 8,181.15	0.01	R 17,592,338.40	26.22	R 7,551,865.54	R 67,097,453.09
BE	2008	R 48,306,298.41	73.41	R 382,599.62	0.58	R 17,118,208.40	26.01	R 6,124,411.16	R 65,807,106.43
BE	2009	R 42,139,088.29	70.68	R 452,242.78	0.76	R 17,029,971.20	28.56	R 3,727,647.12	R 59,621,302.28
BE	2010	R 39,830,574.73	69.60	R 338,950.48	0.59	R 17,054,472.30	29.80	R 1,728,487.60	R 57,223,997.51
BE	2011	R 36,698,974.69	68.31	R 388,566.10	0.72	R 16,638,509.60	30.97	R 3,147,777.56	R 53,726,050.39
BE	2012	R 38,988,158.87	71.50	R 148,000.00	0.27	R 15,390,621.38	28.23	R 2,353,226.67	R 54,526,780.25
Biosciences	2006	R 30,884,294.25	66.91	R 1,303,217.85	2.82	R 13,970,000.00	30.27	R 762,026.20	R 46,157,512.10
Biosciences	2007	R 23,891,076.39	60.08	R 535,167.47	1.35	R 15,340,000.00	38.58	-R 7,883,259.67	R 39,766,243.86
Biosciences	2008	R 23,869,768.35	59.89	R 101,247.22	0.25	R 15,886,470.00	39.86	R 493,049.64	R 39,857,485.57
Biosciences	2009	R 29,949,209.61	65.48	R 86,924.66	0.19	R 15,705,297.08	34.33	-R 132,841.28	R 45,741,431.34
Biosciences	2010	R 22,663,169.77	59.00	R 27,054.84	0.07	R 15,722,470.70	40.93	-R 817,366.81	R 38,412,695.30
Biosciences	2011	R 25,673,505.64	62.10	R 34,888.92	0.08	R 15,633,395.60	37.81	R 550,753.15	R 41,341,790.16
Biosciences	2012	R 20,884,000.67	58.40	R 415,880.00	1.16	R 14,460,890.93	40.44	R 820,950.14	R 35,760,771.60
DPSS	2006	R 72,663,786.19	80.83	R 2,794,634.15	3.11	R 14,437,500.01	16.06	R 9,991,488.04	R 89,895,920.35
DPSS	2007	R 89,255,568.76	80.37	R 5,426,786.54	4.89	R 16,380,000.02	14.75	R 13,250,360.58	R 111,062,355.32
DPSS	2008	R 106,944,935.72	81.99	R 8,601,032.44	6.59	R 14,891,950.00	11.42	R 14,638,288.01	R 130,437,918.16
DPSS	2009	R 121,092,331.59	87.32	R 3,268,567.79	2.36	R 14,318,268.80	10.32	R 17,842,883.90	R 138,679,168.17
DPSS	2010	R 127,636,417.84	88.90	R 2,284,707.61	1.59	R 13,650,515.35	9.51	R 15,699,820.73	R 143,571,640.80
DPSS	2011	R 139,277,283.08	89.74	R 2,599,991.90	1.68	R 13,317,576.00	8.58	R 18,601,577.05	R 155,194,850.98
DPSS	2012	R 133,702,016.09	91.03	R 851,000.00	0.58	R 12,318,757.80	8.39	R 8,716,176.38	R 146,871,773.89
MDS	2006								
MDS	2007								
MDS	2008	R 258,500.00	5.18			R 4,733,501.60	94.82	R 617,897.56	R 4,992,001.60
MDS	2009	R 5,292,591.71	53.25			R 4,646,400.00	46.75	R 674,586.56	R 9,938,991.71
MDS	2010	R 5,576,253.03	54.53			R 4,649,782.53	45.47	R 995,789.36	R 10,226,035.56
MDS	2011	R 7,030,188.65	60.78			R 4,536,373.20	39.22	R 1,653,973.67	R 11,566,561.85
MDS	2012	R 10,731,703.11	71.89			R 4,196,145.21	28.11	R 1,480,476.93	R 14,927,848.32
Meraka	2006	R 38,133,813.07	84.30			R 7,101,600.00	15.70	R 2,969,489.50	R 45,235,413.07
Meraka	2007	R 51,511,718.93	86.47			R 8,061,341.60	13.53	R 8,833,274.85	R 59,573,060.53
Meraka	2008	R 66,542,263.11	91.05			R 6,543,810.00	8.95	R 10,815,785.00	R 73,086,073.11
Meraka	2009	R 86,802,455.63	92.74			R 6,799,173.92	7.26	R 6,107,014.76	R 93,601,629.55
Meraka	2010	R 59,072,705.28	88.67	R 77,900.00	0.12	R 7,470,192.62	11.21	R 3,636,582.97	R 66,620,797.90
Meraka	2011	R 78,294,584.05	91.48	R 4,000.00	0.00	R 7,287,992.80	8.52	R 6,178,410.84	R 85,586,576.85
Meraka	2012	R 77,747,078.47	91.98	R 37,000.00	0.04	R 6,741,393.34	7.98	R 4,497,066.18	R 84,525,471.81
MSM	2006	R 29,953,711.35	54.22	R 597,878.36	1.08	R 24,695,000.01	44.70	R 4,701,340.69	R 55,246,589.72
MSM	2007	R 49,437,403.57	71.30	R 54,046.04	0.08	R 19,845,800.00	28.62	R 6,182,271.09	R 69,337,249.61
MSM	2008	R 49,061,633.55	70.25	R 123,917.60	0.18	R 20,657,440.00	29.58	R 4,549,422.53	R 69,842,991.15
MSM	2009	R 36,253,964.63	63.78	R 163,948.24	0.29	R 20,421,856.86	35.93	R 2,761,550.52	R 56,839,769.73
MSM	2010	R 39,687,234.44	65.83	R 165,393.01	0.27	R 20,436,724.70	33.90	R 2,007,150.75	R 60,289,352.15
MSM	2011	R 37,434,539.15	64.91	R 294,907.05	0.51	R 19,938,268.00	34.57	R 3,090,432.82	R 57,667,714.20
MSM	2012	R 38,187,260.00	67.08	R 296,000.00	0.52	R 18,442,897.90	32.40	R 2,344,535.48	R 56,926,157.90

Unit	Year	Contract Income	Percent Contract	Royalties Income	Percent Royalties	PG Core Income	Percent PG	Net Profit	Total
NLC	2006	R 6,450,182.46	35.75			R 11,594,000.00	64.25	R 353,138.36	R 18,044,182.46
NLC	2007	R 10,487,533.60	56.83			R 7,966,702.64	43.17	R 190,067.21	R 18,454,236.24
NLC	2008	R 13,768,461.46	65.65			R 7,202,750.00	34.35	R 1,170,328.72	R 20,971,211.46
NLC	2009	R 13,328,025.55	65.18			R 7,120,641.44	34.82	R 1,051,910.77	R 20,448,666.99
NLC	2010	R 14,418,797.23	66.93			R 7,125,554.00	33.07	-R 670,794.31	R 21,544,351.23
NLC	2011	R 19,789,296.96	74.00			R 6,951,760.01	26.00	-R 1,590,877.18	R 26,741,056.97
NLC	2012	R 10,132,755.25	49.86			R 10,190,233.24	50.14	R 1,362,006.33	R 20,322,988.49
NRE	2006	R 57,056,299.21	65.96	R 778,301.70	0.90	R 28,663,249.97	33.14	-R 1,854,311.81	R 86,497,850.88
NRE	2007	R 52,469,489.74	64.33	R 392,883.81	0.48	R 28,703,479.98	35.19	R 1,367,554.69	R 81,565,853.54
NRE	2008	R 36,410,450.84	62.94	R 107,599.50	0.19	R 21,327,765.74	36.87	R 6,927,212.75	R 57,845,816.08
NRE	2009	R 36,773,598.32	63.19	R 294,436.55	0.51	R 21,131,827.20	36.31	R 3,502,254.85	R 58,199,862.07
NRE	2010	R 33,338,497.47	60.80	R 355,966.55	0.65	R 21,141,471.22	38.55	-R 1,060,259.83	R 54,835,935.24
NRE	2011	R 38,587,328.10	64.82	R 315,735.74	0.53	R 20,631,425.59	34.65	R 1,415,293.40	R 59,534,489.42
NRE	2012	R 38,375,855.25	66.36	R 371,233.21	0.64	R 19,084,069.05	33.00	R 1,264,331.44	R 57,831,157.51

Appendix 3: Correlation Tables

Correlation Table Key

1. Contract (1995 Rand Value)
2. Royalties (1995 Rand Value)
3. Royalties per Employee
4. PG Core (1995 Rand Value)
5. Net Profit (1995 Rand Value)
6. PG – A
7. Percentage of PG invested in Type A
8. PG – B
9. Percentage of PG invested in Type B
10. PG – C
11. Percentage of PG invested in Type C
12. New Innovation Disclosures
13. New Innovation Disclosures per Employee
14. New PCT Applications
15. New PCT Applications per Employee
16. International Patents Granted
17. International Patents Granted per Employee
18. New Technology Packages
19. New Technology Packages per Employee
20. New Licence Agreements
21. New Licence Agreements per Employee
22. Publications
23. Publications per Employee

Appendix 3a: Correlation Table for Built Environment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	-0.18	-0.25	0.36	0.43	0.54	0.14	0.50	-0.07	0.43	0.00	0.00	0.00	-0.71	-0.71	NA	NA	0.90	0.90	0.11	0.11	-0.83	-0.83
2		1.00	0.96	-0.54	-0.43	0.00	0.32	0.21	-0.07	0.04	-0.39	0.50	0.50	0.35	0.35	NA	NA	-0.30	-0.30	-0.22	-0.22	0.60	0.60
3			1.00	-0.57	-0.57	-0.07	0.29	0.25	-0.04	0.00	-0.36	0.30	0.30	0.35	0.35	NA	NA	-0.40	-0.40	-0.34	-0.34	0.77	0.77
4				1.00	0.75	-0.25	-0.64	-0.07	0.57	0.04	0.54	-0.10	-0.10	-0.71	-0.71	NA	NA	0.70	0.70	0.34	0.34	-0.60	-0.60
5					1.00	-0.29	-0.64	0.18	0.57	0.21	0.50	-0.10	-0.10	-0.35	-0.35	NA	NA	0.80	0.80	-0.11	-0.11	-0.71	-0.71
6						1.00	0.86	-0.07	-0.86	0.18	-0.50	0.50	0.50	-0.71	-0.71	NA	NA	0.20	0.20	0.89	0.89	-0.54	-0.54
7							1.00	-0.21	-0.89	-0.11	-0.79	0.90	0.90	-0.35	-0.35	NA	NA	-0.30	-0.30	0.89	0.89	-0.03	-0.03
8								1.00	0.21	0.75	0.39	-0.70	-0.70	0.00	0.00	NA	NA	0.60	0.60	-0.89	-0.89	-0.09	-0.09
9									1.00	-0.14	0.46	-0.40	-0.40	0.00	0.00	NA	NA	0.50	0.50	-0.89	-0.89	0.09	0.09
10										1.00	0.61	-0.70	-0.70	0.35	0.35	NA	NA	0.10	0.10	-0.22	-0.22	-0.20	-0.20
11											1.00	-0.90	-0.90	0.35	0.35	NA	NA	0.00	0.00	-0.34	-0.34	-0.03	-0.03
12												1.00	1.00	-0.35	-0.35	NA	NA	-0.10	-0.10	0.67	0.67	0.00	0.00
13													1.00	-0.35	-0.35	NA	NA	-0.10	-0.10	0.67	0.67	0.00	0.00
14														1.00	1.00	NA	NA	-0.71	-0.71	-0.40	-0.40	0.71	0.71
15															1.00	NA	NA	-0.71	-0.71	-0.40	-0.40	0.71	0.71
16																NA	NA	NA	NA	NA	NA	NA	NA
17																	NA	NA	NA	NA	NA	NA	NA
18																		1.00	1.00	-0.22	-0.22	-0.90	-0.90
19																			1.00	-0.22	-0.22	-0.90	-0.90
20																				1.00	1.00	-0.11	-0.11
21																					1.00	-0.11	-0.11
22																						1.00	1.00
23																							1.00

Appendix 3b: Correlation Table for Biosciences

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	0.29	0.18	-0.29	0.00	-0.14	0.43	-0.64	-0.43	-0.43	-0.43	-0.09	0.03	-0.29	-0.14	-0.41	-0.37	0.05	-0.43	0.26	0.31	-0.60	-0.49
2		1.00	0.96	-0.71	0.29	-0.64	0.14	-0.43	-0.14	-0.14	-0.14	0.37	0.26	0.41	0.54	-0.46	-0.37	0.79	-0.09	0.62	0.54	-0.83	-0.94
3			1.00	-0.75	0.50	-0.68	0.07	-0.32	-0.07	-0.07	-0.07	0.37	0.26	0.41	0.54	-0.46	-0.37	0.79	-0.09	0.62	0.54	-0.83	-0.94
4				1.00	-0.50	0.96	0.39	-0.07	-0.39	-0.39	-0.39	0.26	0.37	0.38	0.26	0.70	0.60	0.32	0.71	0.09	0.03	0.83	0.66
5					1.00	-0.46	-0.18	0.14	0.18	0.18	0.18	-0.20	-0.09	-0.43	-0.31	0.41	0.49	-0.05	-0.49	0.35	0.43	-0.43	-0.37
6						1.00	0.43	-0.14	-0.43	-0.43	-0.43	0.43	0.60	0.46	0.37	0.61	0.49	0.53	0.83	0.18	0.09	0.77	0.60
7							1.00	-0.93	-1.00	-1.00	-1.00	0.26	0.37	0.55	0.60	0.23	0.26	0.74	0.37	0.97	0.94	0.03	-0.26
8								1.00	0.93	0.93	0.93	-0.26	-0.31	-0.49	-0.60	0.14	0.09	-0.95	-0.14	-0.97	-0.94	0.37	0.60
9									1.00	1.00	1.00	-0.26	-0.37	-0.55	-0.60	-0.23	-0.26	-0.74	-0.37	-0.97	-0.94	-0.03	0.26
10										1.00	1.00	-0.26	-0.37	-0.55	-0.60	-0.23	-0.26	-0.74	-0.37	-0.97	-0.94	-0.03	0.26
11											1.00	-0.26	-0.37	-0.55	-0.60	-0.23	-0.26	-0.74	-0.37	-0.97	-0.94	-0.03	0.26
12												1.00	0.94	0.81	0.83	0.09	0.03	0.95	0.77	0.26	0.03	-0.14	-0.31
13													1.00	0.75	0.77	0.17	0.09	0.95	0.83	0.35	0.14	0.03	-0.14
14														1.00	0.99	-0.07	-0.12	0.95	0.84	0.54	0.35	0.06	-0.23
15															1.00	-0.12	-0.14	0.95	0.77	0.62	0.43	-0.09	-0.37
16																1.00	0.99	0.11	0.20	0.04	0.03	0.38	0.32
17																	1.00	0.11	0.09	0.09	0.09	0.26	0.20
18																		1.00	0.95	0.87	0.74	-0.21	-0.58
19																			1.00	0.26	0.09	0.49	0.26
20																				1.00	0.97	-0.18	-0.44
21																					1.00	-0.14	-0.37
22																						1.00	0.94
23																							1.00

Appendix 3c: Correlation Table for Defence Peace Safety and Security

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	-0.64	-0.75	-0.86	0.43	0.57	-0.36	0.54	-0.04	0.57	0.46	-0.65	-0.77	-0.24	-0.41	-0.10	-0.77	0.87	0.71	-0.44	-0.44	0.94	0.71
2		1.00	0.96	0.89	0.14	0.00	0.64	-0.36	-0.39	-0.29	-0.21	0.47	0.60	0.00	0.00	-0.07	0.20	-0.87	-0.49	0.78	0.78	-0.43	-0.26
3			1.00	0.93	0.00	-0.04	0.71	-0.54	-0.43	-0.36	-0.32	0.56	0.71	0.24	0.26	-0.07	0.37	-0.87	-0.54	0.78	0.78	-0.54	-0.37
4				1.00	-0.11	-0.25	0.61	-0.46	-0.32	-0.39	-0.32	0.35	0.54	0.00	0.12	0.34	0.71	-0.87	-0.43	0.85	0.85	-0.71	-0.43
5					1.00	0.21	-0.14	0.32	0.07	0.21	0.18	-0.44	-0.60	-0.24	-0.41	-0.27	-0.89	0.58	0.49	-0.44	-0.44	0.83	0.54
6						1.00	0.29	0.21	-0.75	0.71	0.57	-0.44	-0.37	0.00	-0.20	-0.03	-0.43	0.29	0.60	0.30	0.30	0.77	0.77
7							1.00	-0.75	-0.79	-0.36	-0.46	0.12	0.26	0.48	0.46	0.17	0.26	-0.58	-0.09	0.85	0.85	-0.20	-0.31
8								1.00	0.29	0.75	0.86	-0.50	-0.54	-0.84	-0.93	0.07	-0.43	0.29	0.49	-0.27	-0.27	0.60	0.83
9									1.00	-0.29	-0.14	0.26	0.09	-0.24	-0.14	-0.27	-0.14	0.29	-0.37	-0.78	-0.78	-0.26	-0.31
10										1.00	0.96	-0.62	-0.60	-0.48	-0.64	0.07	-0.43	0.58	0.71	-0.10	-0.10	0.83	1.00
11											1.00	-0.50	-0.49	-0.72	-0.84	0.07	-0.37	0.29	0.54	-0.10	-0.10	0.66	0.94
12												1.00	0.97	0.23	0.40	0.31	0.03	-0.76	-0.97	0.29	-0.07	0.22	-0.62
13													1.00	0.36	0.41	-0.54	0.20	-0.87	-0.94	0.14	0.14	-0.71	-0.60
14														1.00	0.97	-0.19	0.00	0.15	-0.24	0.00	0.00	-0.20	-0.48
15															1.00	-0.22	0.20	0.15	-0.32	0.03	0.03	-0.32	-0.64
16																1.00	0.68	0.00	0.54	0.53	0.50	0.71	0.07
17																	1.00	-0.29	-0.14	0.51	0.51	-0.71	-0.43
18																		1.00	0.87	-0.65	-0.65	0.87	0.58
19																			1.00	0.03	0.03	0.77	0.71
20																				1.00	1.00	0.18	-0.10
21																					1.00	-0.27	-0.10
22																						1.00	0.83
23																							1.00

Appendix 3d: Correlation Table for Modelling and Digital Sciences

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	NA	NA	-0.90	0.90	0.40	0.20	0.80	-0.20	0.77	0.77	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4				1.00	-0.80	0.20	0.40	-1.00	-0.40	-0.77	-0.77	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5					1.00	0.20	0.40	0.60	-0.40	0.26	0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6						1.00	0.80	-0.20	-0.80	0.26	0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7							1.00	-0.40	-1.00	-0.26	-0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8								1.00	0.40	0.77	0.77	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9									1.00	0.26	0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10										1.00	1.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11											1.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12												NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
13													NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
14														NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
15															NA	NA	NA	NA	NA	NA	NA	NA	NA
16																NA	NA	NA	NA	NA	NA	NA	NA
17																	NA	NA	NA	NA	NA	NA	NA
18																		NA	NA	NA	NA	NA	NA
19																			NA	NA	NA	NA	NA
20																				NA	NA	NA	NA
21																					NA	NA	NA
22																						NA	NA
23																							NA

Appendix 3e: Correlation Table for Meraka

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	-1.00	-1.00	-0.39	0.29	0.50	0.29	0.29	-0.36	0.43	0.07	0.41	0.30	0.58	0.45	NA	NA	-0.10	-0.30	0.30	0.30	0.60	0.80
2		1.00	1.00	0.50	-1.00	0.50	0.50	-0.50	0.50	-1.00	-1.00	-1.00	-1.00	NA	NA	NA	NA	1.00	1.00	1.00	1.00	-1.00	-1.00
3			1.00	0.50	-1.00	0.50	0.50	-0.50	0.50	-1.00	-1.00	-1.00	-1.00	NA	NA	NA	NA	1.00	1.00	1.00	1.00	-1.00	-1.00
4				1.00	-0.14	-0.29	0.36	-0.32	-0.39	-0.21	-0.29	-0.41	-0.20	-0.87	-0.89	NA	NA	-0.46	-0.30	-0.30	-0.30	0.40	-0.20
5					1.00	0.57	-0.61	0.89	0.46	0.96	0.79	0.36	0.30	0.29	0.45	NA	NA	0.62	0.70	-0.70	-0.70	-0.20	0.40
6						1.00	0.07	0.57	0.04	0.61	0.14	0.31	0.10	0.87	0.89	NA	NA	0.56	0.40	0.60	0.60	-0.80	-0.40
7							1.00	-0.64	-0.89	-0.50	-0.79	-0.36	-0.30	-0.29	-0.45	NA	NA	-0.62	-0.70	0.70	0.70	0.20	-0.40
8								1.00	0.68	0.79	0.57	0.67	0.60	0.58	0.67	NA	NA	0.87	0.90	-0.50	-0.50	-0.40	0.20
9									1.00	0.29	0.46	0.56	0.50	0.58	0.67	NA	NA	0.97	1.00	-0.20	-0.20	-0.80	-0.40
10										1.00	0.82	0.21	0.10	0.29	0.45	NA	NA	0.36	0.40	-0.60	-0.60	-0.20	0.40
11											1.00	0.21	0.10	0.29	0.45	NA	NA	0.36	0.40	-0.60	-0.60	-0.20	0.40
12												1.00	0.97	0.74	0.63	NA	NA	0.66	0.56	-0.21	-0.21	0.00	0.40
13													1.00	0.58	0.45	NA	NA	0.56	0.50	-0.30	-0.30	0.00	0.40
14														1.00	0.97	NA	NA	0.74	0.58	0.29	0.29	-0.45	0.00
15															1.00	NA	NA	0.80	0.67	0.22	0.22	-0.63	-0.11
16																NA	NA	NA	NA	NA	NA	NA	NA
17																	NA	NA	NA	NA	NA	NA	NA
18																		1.00	0.97	-0.05	-0.05	-0.80	-0.40
19																			1.00	-0.20	-0.20	-0.80	-0.40
20																				1.00	1.00	-0.40	-0.80
21																					1.00	-0.40	-0.80
22																						1.00	0.80
23																							1.00

Appendix 3f: Correlation Table for Material Science and Manufacturing

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	-0.75	-0.86	-0.32	0.14	0.75	0.68	0.07	-0.14	0.75	0.04	0.83	0.83	0.62	0.64	0.23	0.23	0.75	0.75	0.26	0.32	0.09	0.09
2		1.00	0.96	0.14	-0.29	-1.00	-0.86	-0.14	0.32	-0.21	0.39	-0.60	-0.60	-0.24	-0.29	-0.41	-0.41	-0.93	-0.93	-0.68	-0.75	0.09	0.09
3			1.00	0.11	-0.21	-0.96	-0.75	-0.21	0.21	-0.32	0.32	-0.77	-0.77	-0.35	-0.38	-0.32	-0.32	-0.84	-0.84	-0.53	-0.58	-0.03	-0.03
4				1.00	0.18	-0.14	-0.43	-0.04	-0.14	-0.57	0.07	-0.09	-0.09	-0.68	-0.64	0.03	0.03	-0.32	-0.32	-0.06	-0.14	-0.26	-0.26
5					1.00	0.29	0.36	-0.71	-0.89	0.00	0.39	-0.14	-0.14	0.15	0.23	-0.49	-0.49	0.20	0.20	-0.29	-0.14	-0.89	-0.89
6						1.00	0.86	0.14	-0.32	0.21	-0.39	0.60	0.60	0.24	0.29	0.41	0.41	0.93	0.93	0.68	0.75	-0.09	-0.09
7							1.00	-0.14	-0.46	0.43	-0.18	0.49	0.49	0.38	0.46	0.41	0.41	0.93	0.93	0.56	0.67	-0.14	-0.14
8								1.00	0.86	-0.21	-0.82	0.37	0.37	0.32	0.23	0.46	0.46	-0.06	-0.06	0.15	0.03	1.00	1.00
9									1.00	-0.07	-0.50	0.20	0.20	0.12	0.03	0.41	0.41	-0.29	-0.29	0.03	-0.12	0.94	0.94
10										1.00	0.46	0.77	0.77	0.62	0.64	0.00	0.00	0.58	0.58	0.00	0.06	-0.09	-0.09
11											1.00	-0.03	-0.03	-0.09	-0.06	-0.64	-0.64	-0.12	-0.12	-0.44	-0.38	-0.77	-0.77
12												1.00	1.00	0.44	0.46	0.55	0.55	0.67	0.67	0.35	0.32	0.37	0.37
13													1.00	0.44	0.46	0.55	0.55	0.67	0.67	0.35	0.32	0.37	0.37
14														1.00	0.99	-0.01	-0.01	0.22	0.22	-0.36	-0.31	0.32	0.32
15															1.00	0.06	0.06	0.32	0.32	-0.31	-0.25	0.23	0.23
16																1.00	1.00	0.65	0.65	0.75	0.69	0.46	0.46
17																	1.00	0.65	0.65	0.75	0.69	0.46	0.46
18																		1.00	1.00	0.72	0.78	-0.06	-0.06
19																			1.00	0.72	0.78	-0.06	-0.06
20																				1.00	0.99	0.15	0.15
21																					1.00	0.03	0.03
22																						1.00	1.00
23																							1.00

Appendix 3g: Correlation Table for The National Laser Centre

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	NA	NA	-0.89	-0.93	-0.57	0.21	-0.32	0.21	0.39	0.64	0.39	-0.29	-0.70	0.00	-0.11	0.71	0.71	0.00	-0.30	NA	NA	0.80
2		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4				1.00	0.93	0.50	-0.29	0.32	-0.29	-0.36	-0.54	-0.25	0.87	1.00	-0.29	-0.34	-0.71	-0.71	0.00	0.30	NA	NA	0.00
5					1.00	0.46	-0.04	0.54	-0.46	-0.61	-0.64	-0.39	0.58	0.90	-0.29	-0.22	-0.71	-0.71	0.00	0.40	NA	NA	-0.60
6						1.00	0.11	0.04	0.11	0.07	-0.64	-0.75	0.29	0.50	0.00	0.11	-0.71	-0.71	-0.58	-0.10	NA	NA	-0.60
7							1.00	0.18	-0.14	-0.21	0.04	-0.29	0.29	0.70	-0.58	-0.45	-0.35	-0.35	0.29	0.70	NA	NA	-0.80
8								1.00	-0.96	-0.96	-0.71	-0.57	0.29	0.60	-0.58	-0.45	-0.35	-0.35	0.00	0.50	NA	NA	-0.80
9									1.00	0.93	0.61	0.43	-0.29	-0.50	0.87	0.78	0.00	0.00	-0.29	-0.70	NA	NA	0.40
10										1.00	0.61	0.43	-0.29	-0.70	0.58	0.45	0.35	0.35	-0.29	-0.70	NA	NA	0.80
11											1.00	0.89	0.00	-0.30	0.29	0.11	0.35	0.35	0.29	-0.20	NA	NA	0.80
12												1.00	0.00	-0.30	0.29	0.11	0.35	0.35	0.29	-0.20	NA	NA	0.80
13													1.00	0.87	-0.17	-0.32	-0.61	-0.61	-0.17	0.00	NA	NA	0.45
14														1.00	-0.29	-0.34	-0.71	-0.71	0.00	0.30	NA	NA	0.00
15															1.00	0.97	-0.41	-0.41	-0.67	-0.87	NA	NA	0.00
16																1.00	-0.40	-0.40	-0.65	-0.78	NA	NA	-0.32
17																	1.00	1.00	0.61	0.35	NA	NA	0.26
18																		1.00	0.61	0.35	NA	NA	0.26
19																			1.00	0.87	NA	NA	0.26
20																				1.00	NA	NA	-0.20
21																					NA	NA	NA
22																						NA	NA
23																							1.00

Appendix 3h: Correlation Table for Natural Resources and the Environment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	0.71	0.43	0.32	-0.36	-0.71	0.64	-0.93	-0.71	-0.61	-0.36	0.15	0.20	0.00	0.11	-0.32	-0.21	-0.15	-0.20	-0.35	-0.35	0.40	-0.40
2		1.00	0.79	0.36	-0.86	-0.61	0.96	-0.89	-1.00	-0.68	-0.54	0.36	0.40	-0.58	-0.45	-0.47	-0.36	-0.05	0.10	-0.71	-0.71	0.00	-0.20
3			1.00	-0.14	-0.93	-0.75	0.71	-0.64	-0.79	-0.36	-0.18	-0.21	-0.10	-0.29	-0.11	0.00	0.15	0.41	0.60	-0.71	-0.71	0.00	0.50
4				1.00	-0.14	0.29	0.39	-0.25	-0.36	-0.57	-0.86	0.97	0.90	-0.29	-0.45	-0.32	-0.46	-0.36	-0.40	0.35	0.35	-0.20	-0.70
5					1.00	0.54	-0.82	0.61	0.86	0.54	0.46	-0.15	-0.20	0.58	0.45	0.32	0.21	-0.10	-0.30	0.71	0.71	0.00	-0.10
6						1.00	-0.57	0.79	0.61	0.39	0.00	0.67	0.60	0.00	-0.22	0.16	-0.05	-0.05	-0.10	0.71	0.71	-0.20	-0.20
7							1.00	-0.86	-0.96	-0.75	-0.61	0.36	0.30	-0.87	-0.78	-0.79	-0.72	-0.46	-0.30	-0.71	-0.71	-0.60	-0.50
8								1.00	0.89	0.68	0.39	-0.05	-0.10	0.29	0.11	0.47	0.31	0.15	0.10	0.71	0.71	-0.20	0.30
9									1.00	0.68	0.54	-0.36	-0.40	0.58	0.45	0.47	0.36	0.05	-0.10	0.71	0.71	0.00	0.20
10										1.00	0.86	-0.21	-0.10	0.87	0.78	0.95	0.87	0.72	0.60	0.71	0.71	0.80	0.70
11											1.00	-0.62	-0.50	0.87	0.89	0.79	0.82	0.62	0.50	0.35	0.35	0.80	0.70
12												1.00	0.97	-0.15	-0.29	-0.16	-0.29	-0.16	-0.21	0.36	0.36	0.11	-0.56
13													1.00	0.00	-0.11	0.00	-0.10	0.05	0.00	0.35	0.35	0.40	-0.40
14														1.00	0.97	0.91	0.89	0.74	0.58	0.61	0.61	0.89	0.58
15															1.00	0.88	0.92	0.80	0.67	0.40	0.40	0.95	0.67
16																1.00	0.97	0.89	0.79	0.56	0.56	0.95	0.79
17																	1.00	0.95	0.87	0.36	0.36	1.00	0.87
18																		1.00	0.97	0.18	0.18	0.95	0.87
19																			1.00	0.00	0.00	0.80	0.90
20																				1.00	1.00	0.26	0.00
21																					1.00	0.26	0.00
22																						1.00	0.80
23																							1.00

Appendix 3i: Correlation Table for the pooled CSIR data across all eight units

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.00	-0.39	-0.39	-0.86	0.39	0.43	-0.25	0.82	0.86	0.39	0.00	0.21	-0.07	0.34	0.29	0.18	0.29	0.07	0.00	-0.16	-0.11	0.50	0.50
2		1.00	1.00	0.75	0.68	0.04	-0.21	-0.75	-0.57	-0.57	-0.68	0.71	0.75	0.58	0.64	0.57	0.43	0.71	0.68	0.58	0.61	-0.07	-0.07
3			1.00	0.75	0.68	0.04	-0.21	-0.75	-0.57	-0.57	-0.68	0.71	0.75	0.58	0.64	0.57	0.43	0.71	0.68	0.58	0.61	-0.07	-0.07
4				1.00	0.07	-0.29	0.00	-0.93	-0.82	-0.57	-0.29	0.21	0.39	0.09	0.14	0.18	0.07	0.25	0.29	0.41	0.39	-0.21	-0.21
5					1.00	0.36	-0.43	-0.14	0.11	-0.36	-0.75	0.86	0.64	0.76	0.79	0.61	0.54	0.71	0.63	0.45	0.54	0.25	0.25
6						1.00	0.43	0.36	0.25	0.50	-0.07	0.57	0.54	0.45	0.50	0.54	0.43	0.55	0.58	0.70	0.68	0.57	0.57
7							1.00	0.14	-0.43	0.57	0.54	-0.29	-0.11	-0.20	-0.14	0.07	-0.04	-0.16	-0.09	0.18	0.07	-0.04	-0.04
8								1.00	0.75	0.79	0.54	-0.21	-0.36	0.07	0.00	0.04	0.18	-0.24	-0.27	-0.38	-0.39	0.46	0.46
9									1.00	0.32	0.04	0.07	-0.14	0.07	0.00	-0.11	0.04	-0.04	-0.07	-0.20	-0.14	0.46	0.46
10										1.00	0.75	-0.18	-0.11	0.14	0.11	0.29	0.36	-0.05	-0.04	-0.09	-0.18	0.50	0.50
11											1.00	-0.68	-0.57	-0.25	-0.32	-0.11	0.04	-0.58	-0.56	-0.47	-0.57	0.25	0.25
12												1.00	0.93	0.81	0.86	0.75	0.64	0.95	0.92	0.77	0.82	0.43	0.43
13													1.00	0.72	0.79	0.75	0.61	0.98	0.99	0.85	0.86	0.32	0.32
14														1.00	0.99	0.95	0.95	0.78	0.71	0.44	0.45	0.63	0.63
15															1.00	0.96	0.93	0.84	0.77	0.52	0.54	0.57	0.57
16																1.00	0.96	0.78	0.74	0.52	0.50	0.61	0.61
17																	1.00	0.65	0.59	0.34	0.32	0.71	0.71
18																		1.00	0.99	0.76	0.78	0.33	0.33
19																			1.00	0.82	0.83	0.31	0.31
20																				1.00	0.99	0.34	0.34
21																					1.00	0.32	0.32
22																						1.00	1.00
23																							1.00

Appendix 4: Summary of proxy data

Unit	Year	Total Staff	New invention disclosures	New PCT applications	International patents granted	New Technology Packages	New licence agreements	New start-up companies registered	Publications
BE	2006	225							
BE	2007	242	0	0	0	11	0	0	38.5
BE	2008	250	8	0	0	4	3	0	47.5
BE	2009	222	7	0	0	7	0	0	74.5
BE	2010	214	5	0	0	3	2	0	85
BE	2011	203	3	1	0	1	0	0	92.5
BE	2012	185							
Biosciences	2006	179			3				9
Biosciences	2007	242	10	5	2	4	2	1	
Biosciences	2008	220	11	6	21	7	4	0	33
Biosciences	2009	203	9	4	3	4	3	2	34.5
Biosciences	2010	187	1	2	5	3	2	0	40.5
Biosciences	2011	191	6	1	14	3	0	0	32
Biosciences	2012	174							
DPSS	2006	215	9	2	3		0	0	16.5
DPSS	2007	237	5	1	12	5	3	0	20
DPSS	2008	296	7	1	3	5	1	0	42.5
DPSS	2009	302	7	0	3	5	0	0	40.5
DPSS	2010	321	0	0	4	8	0	0	47.5
DPSS	2011	350	5	2	3	8	0	0	49.5
DPSS	2012	353							
MDS	2006								
MDS	2007								
MDS	2008	1							
MDS	2009	42							
MDS	2010	59							
MDS	2011	71							
MDS	2012	79							
Meraka	2006	95							
Meraka	2007	158	5	0	0	8	0	0	
Meraka	2008	172	5	1	0	13	4	0	64
Meraka	2009	207	7	1	0	8	5	0	83
Meraka	2010	219	0	0	0	6	6	0	72.5
Meraka	2011	200	3	0	0	5	2	1	86.5
Meraka	2012	197							
MSM	2006	200	3	0	2	0	0		30.5
MSM	2007	212	8	3	3	6	1	0	50
MSM	2008	223	12	2	9	8	2	1	78.5
MSM	2009	231	6	0	6	4	3	0	84
MSM	2010	238	11	2	4	3	1	0	123
MSM	2011	238	7	6	4	3	0	0	93
MSM	2012	220							
NLC	2006	57							
NLC	2007	63	3	0	0	2	0	0	
NLC	2008	65	3	0	0	1	0	0	32.5
NLC	2009	72	1	1	0	1	0	0	31
NLC	2010	77	3	1	0	1	0	0	54.5
NLC	2011	81	1	0	11	2	0	0	48
NLC	2012	81							
NRE	2006	337							
NRE	2007	338	4	0	0	3	0	0	
NRE	2008	333	3	1	2	4	3	0	144.5
NRE	2009	296	1	0	0	1	0	0	114.5

Unit	Year	Total Staff	New invention disclosures	New PCT applications	International patents granted	New Technology Packages	New licence agreements	New start-up companies registered	Publications
NRE	2010	234	2	0	1	4	0	0	120
NRE	2011	222	1	1	2	6	0	0	147
NRE	2012	199							