The changing role of public research institutes in South Africa

A report to the NRF

DRAFT JANUARY 2015

Education and Skills Development Research Programme

Glenda Kruss

Genevieve Haupt

Azinga Tele

Bongani Nyoka

Christopher Diwu

Rushil Ranchod

PREFACE

The research reported on here will contribute one complementary component to a multi-faceted research agenda focused on problematising the developmental role of universities and public research institutes in the national system of innovation in South Africa, and comparatively, in African contexts. A set of interlocking projects has been designed to map the nature of organisations' and scientists' interaction with external partners – whether firms, government agencies or based in civil society - to study existing ways in which knowledge is transferred, disseminated and utilised. The organisational conditions in distinct types of university or public research institute that support and promote such interaction in the specific policy and contextual settings of each country is a key focus.

The research agenda has two strategic goals:

1. To promote policy dialogue towards an integrated vision of higher education and public research institute contribution to economic and social development, through interaction with and to the benefit of, the private sector, the public sector and social organizations
2. To develop conceptual frameworks and empirical methodologies to investigate innovation and interaction between knowledge producers and users, particularly communities and social partners, in sub-Saharan African contexts

Several large-scale multi-year research projects have already been put in place, towards these goals.

First, a study has been conducted to map the forms of university interaction with external social partners across different types of higher education institutional types, and between different disciplinary fields, in South Africa. A collaborative methodology was designed with participation from the selected universities, centred on a telephonic survey of a large cohort of academics on the ways in which their academic scholarship is extended to the benefit of external social partners (Kruss et al 2012), and a qualitative analysis of their institutional policies, structures and incentive mechanisms.

Second, comparative research in five countries in Sub-Saharan Africa is underway, funded under the Innovation for Inclusive Development program of the Canadian International Development Research Centre (IDRC). This project addresses the question: how do universities contribute to innovation in a way that is more integrated and inclusive of a wider array of social partners – communities, public sector or firms – and academic activities – teaching, research and service – and resonates more effectively with local, national, African and global development imperatives? Specifically, it focuses on innovation with marginalised communities in informal settings, in collaboration with partners in Tanzania, Botswana, Malawi, Uganda and Nigeria.

The complementary focus of the current research project is a theme that has not been addressed systematically in African contexts: the role of public research institutes in the South African system of innovation.

Contents

ACKNOWLEDGEMENTS

The research was funded by the National Research Foundation under the Department of Science and Technology's *Human and Social Dynamic Grand Challenge* funding stream. The financial support is gratefully acknowledged.

In addition, funding from the International Research and Development Council (IDRC) of Canada under the *Innovation for Inclusive Development* programme was used to conduct the surveys of scientists and academics. The possibilities thus established for comparative work and synergy are valuable.

The project provided an opportunity for research training in the Education and Skills Development programme at the HSRC. Dr Rushil Ranchod contributed to the project as part of his post-doctoral fellowship, providing leadership for the process of access and fieldwork, and drafting an analysis of the policy context. Genevieve Haupt, a doctoral intern, conducted fieldwork at the MRC, ARC, and Mintek, worked on data analysis and drafted data analysis sections of the MRC and ARC, and managed the fieldwork process. Chris Diwu, a doctoral intern, conducted fieldwork at Mintek and drafted the organisational analysis, as well as the organisational analysis of the MRC. Bongani Nyoka, a masters intern, conducted fieldwork and drafted the organisational analysis at CGS and CSIR, and in addition, drafted the analysis of ARC. Azinga Tele, a Masters intern, drafted data analysis of the CGS, prepared the references and worked on the finalising the report.

Tania Fraser provided efficient project management and fieldwork arrangements. The telephonic survey was conducted by Impact Research International, and the excellent leadership of Charlene Flavell must be acknowledged.

Mariette Visser worked with IRI and prepared excellent datasets, mentoring Genevieve Haupt through the initial descriptive data analysis. Katya Mauff of the Department of Statistics at the University of Cape Town collaborated on the analysis of the data, providing expertise and developing our statistical analytical skills. Her patience, thoroughness and creativity in attempting different forms of analysis are acknowledged.

INTRODUCTION

Public research institutes, alongside universities, are key actors in the public science and technology system, to promote a country's innovation and economic development. There is a widespread assumption that universities and public research institutes (PRIs) should play a key role in technological upgrading and learning in developing countries, connecting them to global flows of science and technology (Nelson 1993, Mazzoleni and Nelson 2007, Mazzoleni 2008, Suzigan et al 2015). Globally in recent years, public research institutes are facing changes and growing expectations to be more efficient and more responsive to social needs.

However, as a recent OECD (2011) publication notes, despite these imperatives, there has been little systematic research on PRIs roles, structures, functions and performance in a national system of innovation. This is in contrast to a wide policy and research literature on the roles of universities.

In South Africa, science councils, as public research institutes are known, have existed since the nineteenth century, and historically played roles closely connected to the minerals-energy complex that drove industrialisation. Over the past twenty years, new policy has been introduced to link their mandates more closely to governments' dual objectives to harness science and technology for ''maintaining cutting edge global competitiveness, and addressing the urgent needs of those of our citizens who are less able to assert themselves in the market'' (DST 1996).

We have evidence that science councils have been tasked with new developmental mandates, and that new structural, governance and funding arrangements have been put in place. Science councils are encouraged to create linkages with firms, incentivised through policy and funding instruments such as THRIP or the Innovation Fund (HSRC 2003). In terms of their applied science and technology development mandate, science councils may be expected to interact with firms to a greater extent than universities do. The Innovation Survey 2005 showed that innovative firms in fact regarded science councils (12%) as a less important source of information or cooperative partner for their innovation activities than they did universities (16%) (HSRC, 2005). A similar trend was reflected in the 2008 Innovation Survey (HSRC, 2008). Moreover, science councils are less important collaboration partners than universities for R&D performing firms (HSRC, 2013), who reported 85 collaborative projects with South African universities and 15 collaborative projects with science councils, in the 2009/2010 R&D survey (HSRC, 2013). These trends raise critical questions about their role in innovation and technology development – how important are science councils as knowledge partners for firms? Are they more important knowledge and technology partners for social organisations, communities and civil society, given their public orientation and funding?

There is evidence that at both the policy and systemic level, the mandate of science councils and their operation within the national system of innovation has been problematic. According to national reviews of the Science, Engineering, Technology and Innovation (SETI) system, the shifting mandate of individual science councils has deepened inefficiencies, despite greater weight being accorded to performance monitoring and evaluation (DST 1998, DST 2013). While their overarching role is perceived to be a contribution to 'national priorities', this needs to be read against the push for funding from external sources other than the parliamentary grant, since 1989. It may also be the case that some science councils lack the capabilities to interact effectively with firms, government, communities or other knowledge partners such as universities, nationally or internationally.

Here we face an empirical research gap. We lack an evidence base of the nature and scale or impact of science councils' interaction. Indeed, as noted, and as we will discuss further in Chapter 1, while there is a rich literature on universities and innovation, there is very little on science councils' role in innovation, globally and in South Africa. We do not know the extent and ways in which researchers and scientists in science councils extend their knowledge to the benefit of external partners, nor how their organisational mandates and structures support and promote such interaction with other actors in the national system of innovation.

In sum, the field requires a stronger evidence base of current activity as a foundation for conceptualisating the role of science councils in the South African national system of innovation. We have little empirical evidence on the nature of the external partners and the patterns of interaction in science councils, with their distinctive disciplinary and sectoral foci. A focus on the social and community outreach role in science councils alongside their role in technology development for industry is appropriate. We lack systematic investigation of the extent of interaction with firms and with communities in relation to science councils' research and development activities. What are the diverse forms of such interaction in science councils with distinct legacies, what are the diverse forms of organizational partners, and what are their outcomes? What are some of the successful policy interventions, organisational structures and internal incentive mechanisms that science councils have created, to channel and promote these interactions? What is the potential contribution of such interaction to innovation, poverty reduction and economic development?

We propose to extend and replicate the conceptual framework, design and methodological approach used to study university interaction in the national system of innovation in South Africa (Kruss et al 2012), to address this research gap. Here, we focus on science councils' roles and interaction in the national system of innovation.

Accordingly, the report is structured into nine chapters. Chapter 1 provides a review of the literature and presents the innovation systems framework used in the research. Chapter 2 goes on to situate science councils in historical context, tracing their emergence in relation to shifts in South African science and technology and innovation policy. Chapter 3 describes the design and methodology of the data gathering process, as well as the data analysis.

Then follows a set of five chapters, analysing each of the five science councils included in the study. Chapter 4 begins with an analysis of the Council for Scientific and Industrial Research, the most well established PRI with the strongest research and innovation reputation nationally and globally, under the leadership of the Department of Science and Technology. Chapter 5 identifies patterns of interaction in the Council for Mineral Science, Mintek, which caters to the minerals and energy sector at the heart of the South African economy, reporting to the department of Minerals and Energy. Chapter 6 focuses on the Council for Geo Science, while Chapter 7 describes the Agricultural Research Council and Chapter 8, the Medical Research Council, all of whom report to their line departments.

Chapter 9 concludes by comparing patterns of interaction across the five science councils in relation to their response to national policy imperatives, comparing the ways in which they promote and support the development of interactive capabilities on the part of their scientists and academics.

CHAPTER 1. Literature review and conceptual framework

For the present study, we proposed to replicate the framework and design used to study academic interaction in universities. To do so required an examination of the literature, to inform how the framework could be extended to study public research institutes, and identify what adaptations may be required. This chapter first describes trends in the South African and international literature on public research institutes, before setting out the framework used to inform data gathering and analysis, customised to foreground the substantive nature of public research institutes in the national system of innovation.

A brief review of the literature on public research institutes

When we began background research for the present project, we were surprised to find how little systematic research has been conducted on science councils as the key public research institutes in the South African national system of innovation. Further searches suggested that public research institutes – as opposed to universities - do not feature strongly as the subject of research in the international literature, a trend increasingly recognised recently.

The local literature

A search of the local literature yielded very few published research articles on science councils. We identified a series of articles published in the South African Journal of Science, particularly in the early 1990s at the time of policy transition. These are primarily reflective in nature, considering the existing and ideal roles, functioning and funding of science councils in a shifting policy landscape (SAJS 1987; SAJS 1992; SAJS 1994; Clark and De Wet 1995; Scholes et al 2008). The return on investment at science councils was a particular concern (for example, Thirtle et al 1998), as was the drive towards 'commercialisation', perceived as leading to the death of science in science councils (Lutjeharms and Thomson 1993) or alternately, their role as technology organisations in the national system innovation (Yannakou 2003).

A useful, though not always accessible[1], primary source is the science, engineering and technology institution (SETI) reviews conducted by the DST for all science councils, every five years. Other policy sources are sections of the periodic reviews of the national system of innovation dedicated to consideration of the level of development and contribution of science councils (DST 1998, NACI 2005, OECD 2007, DST 2012).

Science councils themselves have produced a limited number of publications reflecting on their organisational histories, typically commissioned to celebrate significant anniversaries (Basson 1996; Deeplaul and Bryson 2004; Walwyn 2006, CSIR; History of MRC).

The research report can thus contribute to a gap in our understanding of science councils as key actors in the South African national system of innovation.

The international literature

A search of the international literature on public research institutes revealed a concern to understand the shifting mandates, role, funding and organisation of PRIs, in a number of

[1] The CSIR considers the SETI reviews to be confidential organisational documents and do not make them available, even for research purposes.

advanced economy contexts. In the innovation systems literature, PRIs are typically researched alongside or in contrast to universities and other public or private sector research organisations, in terms of their roles as part of the public research system, in relation to firm learning and technological capability building (Tether and Tajar 2008). We examine each of these trends in turn.

Recent research on the shifting nature of PRIs in OECD economies

Recently, public research institutes appear to be of interest for innovation policymakers in Europe and the OECD advanced economies, evident in a flurry of research reports (a growing ʻʻgreyʼʼ literature) that focus on classification and clarification of the role and nature of public research institutes, in the face of multiple challenges such as funding constraints, open source innovation, and competition with universities (NIFU 2001, PREST 2002, ERA 2005, EU 2007, EU 2011, OECD 2011). Note that there is also a growing interest in ʻʻresearch councilsʼʼ, which refers to funding granting councils that play a very different role, as they are not typically research performing (see for example, Slipersaeter et al 2007 for a comparative review of the research councils in Austria, Norway and Switzerland).

Van Rossum (1994) provided a possible explanation for this trend of growing interest. Research councils, while they are statutory bodies, have always had a free reign to determine what is scientifically 'of strategic value to economic development', which changed or otherwise ended from the 1980s onwards.

The change in the economies of developed nations modified the presuppositions about the role of government in the development of fundamental science. Government policy on fundamental science was no longer defined in laissez-faire terms, but was conceived as the active search for – and subsequent support of – those scientific fields considered to be of strategic value to economic development (Van Rossum 1994: 64).

The focus is now on identifying how public research institutes can play a more effective role in economic development, and how firms, government and other knowledge actors can form more effective linkages with PRIs. The European Research Advisory (ERA) Board, for example, recommended advocacy around the potential complementary role of publicly funded, mission-oriented ʻʻresearch and technology organisationsʼʼ in regional innovation systems (EURAB 2005).

The ERA (2007) further initiated research to create an inventory of these public ''research performing organisations'' across Europe, to identify challenges and promote more effective cooperation. A more recent European Commission (2011) report found a structural shift towards greater R&D expenditure in universities than public research organisations, in a number of the EU-15 countries.

One issue of concern was the transformation of and changing boundaries between universities and public research institutes. An OECD (2008) study worked with an expanded notion of research organisations that ''serve public objectives'', to describe the PRI sector and the ways in which it was changing, in terms of mandates, organisational forms, funding, collaborative interaction, scientific impact and relevance, in the face of market-like operational models. San-Mendenez and Cruz-Castro 2002 for example investigated how Spanish PRIs were responding to a decline in funding support, and found that responsiveness was linked to the degree of autonomy, internally of scientists, and organisationally in relation to government. Others conducted research to inform the more effective functioning of public research institutes in relation to firms: Barg-Gil et al (2007) in the context of Spanish Technology Institutes; and Lyall et al (2004) measured the impact of research conducted in public sector research organisations, in terms of its relevance and value to end-users. Geffen and Judd (2004) investigated mechanisms to enhance the organisational effectiveness of ''public sector research organisations'' in the USA.

These policy-oriented concerns are echoed in the small emerging research literature in advanced economies. Simpson (2004) studied organisational transformation in public science research organisations in New Zealand, in response to a ''modernising'' political agenda and the introduction of a ''New Public Management'' approach to efficiency and transparency. There, the design of the system shifted from a discipline-based structure, to a vertically integrated structured designed to address all the research and technology needs of end-users. In the context of Australia and New Zealand, Stewart (1995) reviewed a range of models for setting research priorities, arguing that systemic incentives and individual choice should be inter-related. Farina and Preissi (2000) studied changes in ''research technology organisations'' roles in innovation systems, in relation to the emergence of a ''highly differentiated service economy'' in Germany, focusing on the challenges of a public/private dichotomy. Similarly, Bienkowska et al (2010) analysed the implications of public-private niche roles, collaboration and balance for innovation systems in Sweden. In the Italian context, Coccia (2005) argued that given the funding constraints and changes in strategic focus, there was a need to develop new metrics to assess the performance of PRIs.

In summary, the literature reflects policy makers and researchers grappling with contemporary substantive shifts in the social compact between knowledge institutions, users and society. As Cadenas and Vessuri (2012) argued in the context of realigning public research with new developmental goals in Venezuela:

> "We live in an era of rethinking science and science institutions, its forms of organisation for the production and distribution of knowledge and many of its central aspects in societies which have grown more complex and which require and demand greater participation by citizens in issues concerning their well-being and the future of the planet…."

Universities and public research institutes are expected to be more accountable and responsive to society, the state and the market. To investigate the forms these imperatives take in the South African context, we turned more systematically to the literature on national systems of innovation, which has paid increasing attention to the central role education and knowledge institutions play in the ability of a country to 'catch-up' or fall behind the leading economies (Nelson 2007, Fagerberg & Verspagen 2007). Sharif (2011) argued that research technology organisations in Asia and Europe are in the process of a transition from their traditional roles, driven by the imperatives of commercialisation and internationalisation, which has catalysed research on their roles in catch-up.

PRIs in the innovation systems literature

A high level of R&D investment and high-level skills is hypothesised to explain the ability of some developing countries, typically newly industrialising countries such as South Korea, Taiwan and Malaysia, to succeed in 'catching-up' with leaders in the developed countries (Nelson 2007, Abramovitz 1986). Academics and policy makers focus on university and public research institutes' potential role as knowledge producers in learning and building technological capabilities in firms, and hence, to a more direct contribution to competitiveness, growth and development (Mazzoleni 2008, Albuquerque 2001, World Bank 2009, Whitley 2002). The interest is in how knowledge institutions may be a source of innovation and change for firms in distinct sectors, and how the interaction among actors in networks plays a role in catch-up (Malerba & Nelson 2007, Schiller & Brimble 2009, Saad & Zawdie 2011). For Mazzoleni and Nelson (2007: 1513), public research institutions are critical in supporting what they call 'social technologies' - the 'organizational forms, bodies of law, public policies, codes of good business and administrative practice, customs, norms.' Thus in order to build a thriving environment for physical technologies, an effective system of higher education and public research ought to be encouraged. When such mechanisms are in place in developing countries' national systems of innovation, they will be able to play 'catch-up' with developed countries. Intarakumnerd (2011) for example, undertook case studies of two distinct national models of the role of research technology organisations in technological catch-up, to inform policy in developing countries.

Radosevic (2011) however, provides a critical caution against an uncontextualised ''transfer of the policy models developed for countries at the technology frontier'', which can have very different, and very little impact, in the realities of other economies. In a middle income country like South Africa, with a great socio-economic divide and high rates of unemployment, the large informal and 'survivalist' sector, and community development initiatives, are significant features of the conditions within which universities and PRIs interact. That is, the range of external partners with which universities interact to play a role in development is wider than and not restricted to, firms in industrial sectors. It could include actors in the informal sector, cooperatives, communities, small scale farmers, social movements and even, individuals and households (Kruss, Adeoti & Nabudere 2009, Lorentzen 2011). At the same time, universities and public research institutes are challenged to address issues of human and social development, to focus equally on capability building for 'freedom from want' such as food insecurity or disease. Mobilising science, technology and innovation to address problems of health, environmental sustainability and agricultural productivity is a priority and key challenge (Conway & Waage 2010).

Drawing on the innovation systems literature, the basic assumption underpinning our research approach is thus that a comprehensive focus on PRI roles in inclusive social and economic development is required.

Conceptual framework

Essentially, this is a replication study, extending the conceptual approach and methodology used for investigating university interaction. Hence, in this section, we set out the framework developed to guide data gathering and analysis for that purpose (Kruss et al 2012, Kruss 2013)2. The framework focused on interaction, capabilities, learning and innovation. At its core, it provided a conceptual basis to identify forms of interaction, and their associated benefits or risks for institutions and the national system of innovation as a whole, for private benefit and public good. It extended this framework to include social and economic development imperatives, and a wide range of external partners. A stronger conceptualisation of universities as knowledge producers, and concepts to understand organisational changes, were added. This approach had to be adapted to take the distinctive nature of public research institutes into account. Here, we describe the university framework, and then in the following section, consider the distinct nature of PRIs to inform the process of adaptation.

Universities and public research institutes in the national system of innovation

Figure 1.1 below provides one way of representing the public science system (left hand side of the diagram) in relation to the industrial system (right hand side of diagram) in a national system of innovation (Von Tunzelmann 2010). The public science system consists of public research institutes, together with education and the university system, interacting with both government, and with firms and the industry structure. Collaboration and alignment between universities and science councils is critical to strengthen immature national systems of innovation in developing countries (Mazzoleni, 2008). The box for ‘’Firms and Industry Structure’’ can be defined to include other formal and informal productive agents, such as small

[2] This section draws extensively on G. Kruss Reconceptualising engagement. A conceptual framework for analysing university interaction with social partners. *South African Review of Sociology*. 43(2): 5-26.

scale and subsistence farmers, SMMEs, community-based and social enterprises or cooperatives.

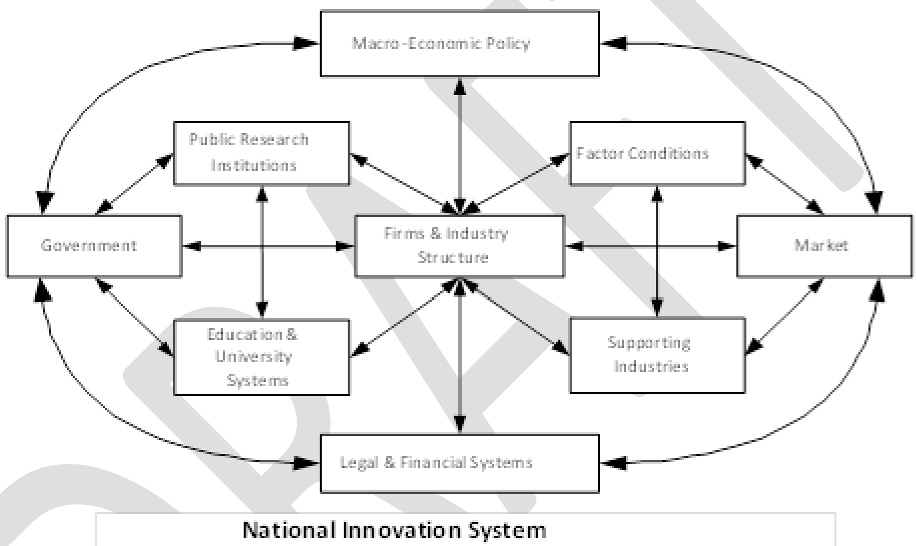


Figure 1.1. Schematic representation of a national system of innovation

Flows of knowledge and capabilities

The work of Cohen, Nelson & Walsh (2002) on the links between and impact of universities on firm R&D in the United States was influential in shaping a body of research in developing countries. Cohen et al's aim was to identify flows of knowledge and capabilities and the advantages of and constraints on building interactive relationships. Hence, it emphasised the fields and sectors, the channels, and the outcomes and benefits to firms of interaction with universities. This approach was adapted to frame research on the nature of interaction between firms and universities in Brazil (Albuquerque et al. 2008, Rapini et al. 2009). A survey instrument was designed to investigate the types of relationship, channels, outcomes and benefits, and barriers, to interaction with firms. The instrument aimed to map university-firm interaction across a national system of innovation, to inform policy. It was subsequently adapted to study the nature and patterns of firm's interaction with universities and public research institutes, and universities and public research institutes interaction with firms, in selected sectors in developing countries in Latin America, Asia and Africa (Adeoti & Odekunle 2010, Arza & Vazquez 2010, Dutrénit et al. 2010, Dutrénit 2010, Eom & Lee 2009, Eun 2009, Fernandes et al. 2010, Intarakumnerd & Schiller 2009, Joseph & Abraham 2009, Orozco & Ruiz 2010). The focus – and empirical entry point - was to investigate universities' and public research institutes interactive practices. This instrument was adopted with some contextualisations, at the heart of the present study.

From firms and research to teaching and other partners

The approach and instrument were adapted to be appropriate in Southern African contexts, to map universities' interaction with firms in a number of SADC countries. The concern was that these universities were relatively young, for the most part had a strong teaching focus, did not have a strong science and technology research base, and in general, had low levels of research activity. Items were thus added to determine the existence of interaction and collaboration in general, with a wider range of partners than firms. In addition, items were added to reflect the teaching focus more strongly and not only research activity, as well as more tacit and less formal forms of interaction (Kruss & Petersen 2009). This process of adaptation provided a useful precedent for the present study.

Channels, benefits and risks

The Latin American work developed a framework to identify forms of interaction, and link channels with the associated benefits and risks of interaction in developing country contexts (Arza 2010, Dutrenit & Arza 2010). Channels of interaction were classified into four broad types, distinguished by the combinations of goals that motivate firms (passive or proactive innovation strategies) and universities (economic / financial or intellectual strategies) to interact. Interaction motivated by the economic strategies of universities and passive strategies of firms is more likely to take the form of 'service' channels, whether scientific or technological, where knowledge flows mainly from the university to the firm. Examples are consultancy or testing or quality control.

In contrast, interactions motivated by the intellectual strategies of the university and proactive strategies of firms are more likely to take 'bi-directional' forms, where knowledge flows are two-way and there is a high potential for joint learning. Examples are joint R&D projects or networks. 'Traditional' forms of interaction are driven by the intellectual imperatives of the university and the passive strategies of firms, with knowledge flows to firms but defined strongly by academic functions, such as hiring graduates, conferences and publications. They may also take the form of financial flows from firms to support the academic function, such as endowments of facilities or chairs or scholarships. These channels are indirect, in that they are available freely in the public realm, and do not require a personal exchange. Finally, 'commercial' forms of interaction are driven by the economic strategies of universities and the proactive strategies of firms, taking the form of spin-off companies or incubators that, like the bi-directional channels, require direct personal interaction at critical stages.

Arza (2010) points to research that highlights that benefits and risks may be social, and may impact on knowledge generation and dissemination in the national system of innovation, particularly in developing countries (Nelson 2004, Lundvall et al. 2009). Certain channels of interaction may lead to the risk of diverting research agendas from topics that may be more socially useful. In health research, for example, this may mean a focus on lucrative clinical trials for pharmaceutical companies to deal with 'lifestyle' diseases of the rich, rather than clinical interventions to deal with resistant strains of tuberculosis amongst the poor.

These concepts allow for the identification of benefits and risks of different forms of interaction for a university or public research institute, and for the national system of innovation as a whole, which is a potentially important strategic tool.

Universities as knowledge-based institutions

A potential weakness of the national systems of innovation literature is a tendency to focus on universities only in relation to their roles in firm learning, technological upgrading and innovation, whether in the form of human resources, R&D, training or technological expertise, which leads easily to charges of instrumentalism. The significance of a focus on the substantive nature of universities is increasingly recognised (Whitley 2003, Kruss 2011, Schiller & Brimble 2009). It is difficult to conceptualise universities in the same way as economic institutions, because of their distinct forms of governance and the multiple roles they play (Mowery & Sampat 2005).

A stronger analytic framework is required to understand the roles of universities within a national system of innovation, for which we drew on the work of Clark and Whitely.

Clark (2008) argued that the 'knowledge-base' of universities, particularly, the discipline-centred nature of academic work, is distinctive to their nature. Disciplinary fragmentation is the source of rapidly growing complexity and 'substantive growth' in higher education systems, as opposed to the 'reactive growth' driven by increases in students or labour market demand: 'academic territories are first of all subject territories, even while they are clientele territories and labour market territories' (Clark 2008: 452). Substantive growth is led by knowledge and research generation, requiring postgraduate expansion and academic specialities, while reactive growth is led by student demand and enrolment, relating to massification of higher education and the demand for undergraduate education, remedial, and introductory teaching. These may be in tension within parts of an institution and may lead to growing segmentation within a differentiated national higher education system. The situation of individual institutions within the national system, and as a national system, with other countries, thus becomes more competitive.

A similar conclusion was reached by Whitley (2000, 2003) who argued that universities are fundamentally 'reputationally controlled work organisations', in that their production of knowledge is structured by academics' competitive pursuit of intellectual reputations, judged by their peers. National systems can be distinguished depending on the intensity of reputational competition and the extent of intellectual pluralism and flexibility - which impact on the degree to which research is coordinated between different kinds of institutions (those with stronger and weaker reputations), and the openness to new research goals, approaches and programmes to address new kinds of (social) problems. In a highly differentiated and segmented system with strong reputational competition between research universities and applied research institutions for example, hierarchies of institutions typically limit and restrict what is possible in setting new research agendas, novelty is restricted, the flow of knowledge between different kinds of institution is limited, and mobility between institutions is difficult without loss of reputation.

These competitive dynamics weaken the development of capabilities and interaction across the system and hence, the national system of innovation as a whole. The nature of differentiation and what is possible for different kinds of university or public research institute within a public science system, is significant for understanding the scale and forms of interaction that prevail.

For universities, the framework was thus built on the premise that responding to external partners is of greater benefit and less risk when it is driven by substantive growth – when it is integral to the expanding knowledge-base of a discipline, to the work of scholarship, and research-based teaching and learning in a university.

A definition of academic interaction focused on 'extending knowledge resources' was thus adopted, to underpin the empirical research instrument:

…a form of scholarship that cuts across teaching, research and services. It involves generating, transmitting, applying and preserving knowledge for the direct benefit of external audiences in ways that are consistent with university and unit missions (Michigan State University 1993; see Cooper 2011).

Analysing institutional conditions

Individual universities respond to changing imperatives in different ways, and are challenged to change their missions, policies, structures and incentive mechanisms to promote interaction. The ability of a university - or public research institute - to respond to change and be flexible and adaptive in how it organises is critical to its role in innovation. Empirical analysis of the policies, culture and organisational structures of an institution was thus included in the study of universities. A key distinction was drawn between internal and external interface structures (Martin 2000). Internal interface structures are dedicated forms of organisational development created within a university or public research institute to support interaction, such as dedicated managerial posts, a dedicated office to promote innovation, engagement or research, technology stations, contracts offices, or IP offices. External interface structures play a similar role but typically have a separate legal status, to enhance flexibility and responsiveness, and to create a more professional interface, such as incubators, science parks, or university owned companies. There has been a high degree of experimentation with these forms of interface structure, shaped by a university's location, research strengths and academic culture (Kruss

2005). An empirical task will be to identify the distinctive organisational forms that promote and support PRI interaction with other actors in the national system of innovation.

A framework to guide data gathering and analysis

We extend this framework to map patterns of interaction of public research institutes with firms, social partners and government.

The approach can be used to map the scale of interaction amongst all academics and scientists within a public research institute, and then, to identify the main forms of interaction that do occur, the main type of external social partners and the main benefits and outcomes associated, relative to the organisational mandate or in specific disciplinary and technology fields. Comparison of patterns of interaction across different types of public research institute in relation to the national system of innovation is then possible.

On closer inspection, the literature on firm interaction in developing countries tended to conflate universities and public research institutes, treating them as if they played the same roles. For the most part, these authors did not systematically analyse or compare the distinctive roles of public research institutes and universities, a conflation that cannot be simply assumed. The challenge is to identify the distinctive nature and multiple roles of public research institutes in the national system of innovation, to ''customise'' the analytical framework appropriately.

The distinctive nature of public research institutes?

There is general agreement in the research literature that public research institutes play a distinctive role in the national system of innovation that stands in contrast to that of universities, or to firms, and private research organisations. Here we review some of the arguments to inform a working definition of what is distinctive, bearing in mind that empirical study in the South African context may add further layers.

Governance features are often used to define and distinguish public research institutes from other knowledge institutions:

- They are typically public, not for profit
- They are typically managerially independent, particularly in setting their own research agendas

- They typically have a mixed funding structure (Leitjen, 2007).

However, these features may equally hold true for universities in the current global context, so do not suggest meaningful grounds for distinction. Varying degrees of 'publicness' is nonetheless a widely shared defining feature of PRIs in the literature.

More appropriate for current purposes is a focus on the distinctive knowledge functions and relationships of public research institutes. A widely accepted and very simple European definition is that PRIs provide:

…research and development, technology and innovation services to enterprises, governments and other clients (European Association of Research and Technology Organisations).

A related but more expanded definition is that public research institutes are best defined by their typical knowledge functions and activities that focus on a mix of:

- Fundamental and strategic or applied research
- Technological support to economic development
- Supporting public policy
- Setting and monitoring technical norms, and standards
- Constructing, operating, and maintaining key research facilities (EURAB 2005)

This suggests that interaction with external partners and 'users' is integral to the mandate of PRIs, and that their knowledge related activities span the full range of basic and applied research, to technology development and innovation.

On a similar basis, OECD (2008) research recognised the growing diversity of public research organisations, and identified four ideal types:

- Mission oriented centres owned by government departments, to support policy making in specific sectors
- Public research centres and councils that perform and fund basic and applied research in several fields
- Research technology organisations that focus on the development and transfer of science and technology to firms and social partners, and may be semi-public

- Independent research institutes that perform basic and applied research focused on specific issues or problems, rather than knowledge fields, which may be semi-public and take on innovative organizational forms.

Each type of PRI performs a variety of roles, in complex combinations, with a trend towards increasing diversification of roles, in response to multiple demands. A major change all face is a reduction in public funding, an emphasis on scientific excellence and the growing demand for responsiveness to firms and social partners. Like universities, PRIs thus differ in their institutional arrangements and capacity to adapt to changes in their environment, to pursue their reputational goals.

How do the diverse roles of public research institutes in middle income developing country contexts differ from those in the advanced economies? Public research institutes were often the first science and technology organisations to be established in developing countries, changing their form and focus as universities developed. As Suizigan et al (2011) argued universities and public research institutes were the first channels to link a country to international flows of science and technology, initially relying on and absorbing knowledge generated in the advanced economies. They demonstrated that the creation of significant universities and public research institutes is strongly correlated with national independence and processes of state-building. These specific origins shape the distinctive role and nature of public research institutes in a late developing country like South Africa:

Late development, by definition, means high levels of poverty, inequality, strong social problems such as slavery, ethnic segregation and colonization. Therefore, since their formation, local universities and PRIs are confronted with great challenges, which determine a ''dual role'' for them, for they must, on the one hand, keep in touch with scientific and technological development at the centre, while, on the other hand, they face various problems and issues (diseases, soils, plant varieties, geological and climate conditions) that need specific investigations and might generate new scientific knowledge (Suizigan et al 2011: 10).

Over time, as new demands and opportunities arise, this dual role of PRIs and universities becomes more complex, and more differentiated. They are required to keep up the connection to international knowledge and technological flows in more, rapidly changing, fields; and to solve more, and more complex, local problems.

This analysis is aligned with our analytical framework, and provides significant pointers towards identifying the distinctive nature of public research institutes in a context like South Africa. Just as change in academic disciplines is the source of rapidly growing complexity and ‘substantive growth’ in universities, change in scientific and technological fields is the source of growing complexity and substantive growth in public research institutes. At the same time, PRIs may face demands from (local) government in the interests of the public good, and from markets that drive reactive growth. We may postulate that responding to external partners is of greater benefit and less risk when it is driven by substantive growth – when it is integral to the expanding knowledge and technology base of a field, to the scientific work, technology development and research-based learning that takes place in PRIs.

In Chapter 4 to 8, we will use this framework to analyse the patterns of interaction and the organisational conditions in five South African science councils. In the next chapter, we provide a historical analysis of public research institutes in South Africa, to contextualise how multiple diversified roles are articulated in current policy imperatives.

CHAPTER 2. Science councils in the South African national system of innovation and development imperatives

To analyse interaction and the diverse roles played by science councils in the South African national system of innovation, we need to understand their historical trajectory relative to economic demand in distinct periods, and the government policy imperatives shaping their strategic mandates over time. This chapter first identifies three distinct periods in which the science councils were established in the South African context, which shaped their nature and focus. It then focuses on the policy shifts and expectations for multiple roles since the advent of a democratic state in 1994. It concludes by determining a generic set of roles that are distinctive to science councils as public research institutes in South Africa.

Three broad waves driving the establishment of public research institutes

A broad historical overview of the formal establishment of the main public research institutes in South Africa, and their precursor organisations, is presented in Table 2.1, to serve as a reference point for the discussion that follows.

Colonial origins, agricultural and mineral focus

As Suzigan et al (2014) found in Latin American countries, South Africa reflects a pattern of late onset of universities and PRIs. The first wave of formal universities and PRIs were established in the late nineteenth century, in response to local developmental challenges in the colonial period. The precursors to the first universities were typically established by the churches as private colleges in the mid to late nineteenth century, to meet the demands of an elite, to train teachers, bureaucrats and other professionals for the colonial economy and government (Mabizela 2000, 2002).

Arguably, the first public research institute established was the South African Astronomical Observatory, which has its roots in an observatory built with great effort and in operation as early as 1829 to guide early trade. This reflects the key role of connecting the ''colony'' to science and technology at the centre, and linking to international knowledge flows. Thus, the drivers for the establishment of the SAAO have been described as:

> … 'the improvement of practical astronomy and navigation' so that the work of the Royal Greenwich Observatory in the north could be complemented by the efforts of His Majesty's Astronomer at the Cape of Good Hope [http://www.saao.ac.za/about/history/].

Scientific resources in this first period were predominantly oriented to support the agriculture-based economy and from the late nineteenth century, the emerging mining industry. Basson's (1996: 13) analysis demonstrates how the pattern of formation was driven by local economic challenges:

> …starting with ad hoc research in a particular discipline to overcome problems of immediate practical importance, leading to the establishment of a research institution. For example. the Veterinary Research Institute at Onderstepoort owes its existence to the outbreak of rinderpest (a cattle disease) in the Transvaal in 1896.

Solving such local problems required scientific investigation and could generate new knowledge in the colony, driving the establishment of public research institutes (Suzigan, et al 2014).

In the period around the union of South Africa in 1910, a key moment in nation-building, we observe the formal creation of new universities, and public research institutes. For example, the precursor to the Council for GeoScience, the National Geographic Survey, was established in 1912, through the merger of three other surveys including the Geological Commission of the Cape of Good Hope, first established in 1898. Similarly, the precursor to the present Water Research commission is the Hydrological Survey initiated in 1910, shortly after political union. The right hand column in Table 2.1 describes the complex organizational history of the current science councils, many of which had their origins in this colonial period, responding to mining and agricultural concerns.

Table 2.1. The establishment of Science Councils in South Africa

PRI	Date formally established in current form	Precursor organisations
Period 2: Industrialisation and big science		
Council for Scientific and Industrial Research	Established in 1945 through the Scientific Research Council Act	There was no equivalent of the CSIR prior to its formation although it can be said that it succeeded the National Research Council and the National Research Board which were established in 1938
Human Sciences Research Council	The HSRC was established as a statutory body in 1968 by section 2 of the Human Sciences Research Council Act 23 of 1968	The HSRC is a ''descendent'' of the CSIR
Africa Institute of South Africa (incorporated into the HSRC 2013)	AISA was established in 1960 as a non-profit organization and became a statutory body in 2001 through the AISA Act number 68 of 2001.	Initially, SA had no equivalent of AISA, which was established to enhance relations with other African countries.
Medical Research Council	Established in terms of the Medical Research Council Act number 19 of 1969	The MRC from inception reported to the Minister of Health. A precursor entity was the SA Institute for Medical Research established in 1912, and a research committee within the CSIR.
Water Research Commission	The WRC operates in terms of the WRC Act 34 of 1971	Following the formation of the Union of South Africa in 1910, a Hydrological Survey was established with the aim to develop more dams and irrigation schemes
Period 3: Marketisation and public accountability		
Council for Mineral	Mintek was established in terms of the Mineral Technology Act 30 of 1989	Among its predecessors may be mentioned the Government

Technology / Mintek		Minerals Laboratory and the Silicosis Medical Bureau formed after the Geological Survey of 1912
Council for GeoScience	Formally established as a science council in 1993, through the Geoscience Act 100 of 1993	Legal successor of the Geological Survey of South Africa, formed in 1912 through the merger of three Surveys, the oldest being the Geological Commission of the Cape of Good Hope established in 1898
Agricultural Research Council	The ARC was established in 1990 through the ARC Act 86 of 1990.	Prior to the formation of the ARC, the Minister of Agriculture relied on the Veterinary Research Institute at Onderstepoort (established in 1908) and departments of agriculture at universities of Natal, Pretoria and Stellenbosch, and the Citrus and Sub-Tropical Fruit Research Station in Nelspruit.
National Health Laboratory Services	The NHLS was established in 2001	Born out of a merger between the SA Institute of Medical Research, the National Centre for Occupational Health and the National Institute for Virology.
South African National Energy Development Institute	SANEDI was established by the National Energy Act number 34 of 2008. As of 31 December 2010 it became a Schedule 3A Public Entity and became operational on 1 April 2011.	SANEDI is the successor to the South African National Energy Research Institute (SANERI) and the National Energy Efficiency Agency (NEEA)
South African National	SANBI was established on 1 September	The forerunner to SANBI is the

Biodiversity Institution	2004 in terms of the National Environmental Management: Biodiversity Act number 10 of 2004.	National Botanical Institute which itself was an amalgamation of the National Botanical Gardens and the Botanical Research Institute in 1989 – both of which were founded early in the 20th century.

Source: compiled by authors

Industrialisation and big science

The second wave, the formal creation of science councils in the form we find them today, began from the 1940s, shaped by the industrialization of the South African economy. Suzigan et al explain that in developing countries, the industrialisation process is accompanied by a new wave of institutional formation as the problems and challenges become more complex. This wave equally reflects global economic and industrial shifts in the post-war period, although they seem to have manifest in South Africa slightly later.

After World War I, governments of the USA, Britain and Germany actively financed industrial research. Of particular interest in South Africa, which remained part of the British Commonwealth until the 1960s, and hence, was strongly influenced by British approaches, was the development of a model for a research council system. The organization that was to become Mintek began its trajectory with the formation of the Mineral Research Laboratory in 1934, a collaboration between government and university.

These processes intensified after World War II, leading to the era of 'big science'. Public research institutes expanded on a large scale throughout Europe and America in that period, to support government policy in sectors such as agriculture, health or defence, and to support industry in terms of technology, infrastructure and regulatory standards (PREST 2002). The CSIR was the initial organisation established in South Africa. Chapter 4 below traces this history in greater depth, illustrating the early tensions around setting research agendas, given that the CSIR was completely funded by government. The CSIR is an instance of a 'public research centre' that performs basic and applied research in a wide range of fields (OECD 2011).

In 1969, the Medical Research Council, previously a centre within the CSIR, was given autonomy and became an independent science council, and in the same period, the Human Sciences Research Council was formed. The history of the MRC will be elaborated in chapter 8 below, but of note, in contrast to the CSIR, it represents an instance of a 'mission oriented centre' owned by a specific government department, to support policy making in a sector (OECD 2011).

Marketisation and public accountability

A third wave of formation of public research institutes in South Africa was shaped by the reconfiguration of the science and technology landscape in terms of the post-apartheid policy of building a national system of innovation to support the development of a democratic state. Again, this is a local mediation of shifting global trends, whereby the role and nature of public research institutes were challenged and became increasingly more complex. Calls for greater accountability to the public good, changing public research priorities and public funding challenges impacted on the role of public research institutes in varying ways in different country contexts globally (PREST 2002, Cox, et al 2001, Poti and Reale 2000). Greater institutional differentiation and complexity has resulted, as science councils respond to these challenges (Leitjen 2007, OECD 2011). The formation of SANBI (2004) and NECSA (2008) to meet changing environmental and energy needs are but two instances of the reconfiguration of the South African national system of innovation after 1994. These represent South African instances of 'independent research institutes' that perform basic and applied research focused on specific issues or problems, and are semi-public, with innovative organizational forms.

However, analysis of Table 2.1 suggests that from the late 1980s, there were already efforts by the apartheid government to respond to these shifting economic and scientific challenges, evident in the formation of ARC (1990), CGS (1993) and Mintek (1989), as 'mission oriented centres'. The scientific focus of these organisations reflects the predominant economic concerns with minerals and agriculture. The global and national knowledge dynamics driving the third wave of change led the apartheid government to introduce a new "Framework Autonomy" system in 19898, intended to compel science councils to become more market aligned. The Framework Autonomy system mandated science councils to seek independent sources of income to complement the parliamentary grant. The rationale was to remove bureaucratic administrative blockages, in order to promote efficiency and allow science councils to be more responsive to external partners and funders. This ended the system under which science councils had been completely funded by government, and hence, made their future control by and relationships to, government more complex. The effective marketization of the public research system was a major push towards interaction with private sector actors and funding agencies, in addition to the government agencies that had been major users of science council research up to that point.

After 1994, the post-apartheid government elaborated the White Paper on Science and Technology (1996) which explicitly adopted the notion of a ''national system of innovation'' as the organizing framework for its vision of change. Public research institutes were redefined as 'Science, engineering and technology' (SETI) institutions, including all performers of R&D and other scientific activities, and identified as key actors. Their role was defined primarily in relation to the technological competitiveness of industry, to undertake research activities that the private sector or universities could not.

> SETIs are … crucial in generating results that lead to innovation in those areas which are not easily or appropriately undertaken in the private sector, for instance, in the areas of pre-competitive research, support of small, medium and micro enterprises (SMMEs), development of high-risk technology, the provision of a national innovation infrastructure, and the support of innovation in the public sector which leads to improvements in professionalism, efficiency and effectiveness (DACST 1996: 24).

The new policy direction centred on a three-fold mandate for public research institutes:

1. to commercialise, and expand the partner base beyond government
2. to raise international profiles, and open global markets
3. to cater for organisations that have been excluded from the benefits of science and technology

The main concern of the new post-apartheid government was that the marketization process initiated by the Framework Autonomy system from 1989 had allowed individual science councils too much autonomy to shape their own research agendas, in ways that were not responsive to new inclusive national priorities. A key policy focus was thus governance and funding. One policy vehicle established by the new dispensation was the Innovation Fund, tasked to reallocate resources toward a mix of economic and social drivers such as “competitiveness, quality of life, environmental sustainability and harnessing information technology.” The Innovation Fund meant that science councils increasingly had to obtain government funding via competitive processes, but more significantly, they were actively encouraged to interact with the private sector, to the benefit of the public good, and to grow collaboration and networks.

A critical mechanism intended to drive change and build the scientific organisations of the NSI was a new performance management system for the SETIs that would seek to advance national goals and priorities, and ensure stronger coordination and alignment across the system, to operate at both institutional and systemic levels. A process of institutional reviews of the resourcing, outcomes and contribution of each science council was proposed to take place every five years to assess their contribution to national priorities and international commitments, their scientific quality and the quality of management.

Public research institutes in a changing policy landscape

In this section, we trace the main policy shifts and emphases in the mandate, governance and funding of science councils over the past two decades, with the focus on how these are intended to drive science council interaction and alignment across the NSI. Table 2.2 summarises the main policy shifts in relation to the mandate of SETIs, and the expectations of interaction.

Table 2.2: Policy shifts in relation to science councils mandate and nature of interaction

Year	Policy activity	Mandate/ functions proposed or emphasised	Nature of or mechanisms to promote interaction and linkages

1996	White Paper on Science and Technology (Department of Arts, Culture, Science and Technology)	Role defined primarily in relation to technological competitiveness of industry, to undertake research activities that the private sector or universities could not A new three-fold mandate: to commercialise and expand the partner base beyond government to raise international profiles and open global markets to cater for organisations that had been excluded from the benefits of science and technology	Encouraged to interact with the private sector, and grow collaboration and networks
1998	SETI Review – System wide	Core Functions: Public interest knowledge and information dissemination Core research infrastructure Human resource development Pre-competitive research Public purpose technology development and diffusion Research, consultancy, services or products	Linkage of public SETIs to smaller scale, less technically- sophisticated national users, clients and stakeholders – small-scale mining, small business, resource poor farmers - a particular emphasis for future growth
2001	SETI Review of MRC		
2002	National Research and Development Strategy (Department of Science and Technology)	The reorientation of science and technology missions to address the dual goals of economic growth and social development emphasised, and hence, the significance of social and private sector partners	State steering of governance, funding and reporting to reorient to national priorities and promote integration and coordination

2003	Review of the 2001/2 Indicator Reports (Department of Science and Technology)	KPAs assessed "technology diffusion/dissemination of information and research results" and the "promotion of networks and linkages" as key objectives. The shift toward greater commercialisation made sustainability and financial indicators essential, as were efficiency indicators. Indicators also included science councils' roles in growing and transforming the "knowledge stock" for science, and contributing to scientific output.	
2003	SETI Review of CGS		
2003	SETI Review of CSIR		
2007	OECD Review of NSI	Contribution to science and innovation for the formal sector emphasised at the expense of the inclusive social development mandate Need for "specialisation and differentiation" particularly in agencies responsible for supporting and performing research and innovation.	
2008	Ten-Year Innovation Plan (Department of Science and Technology)	Five Grand Challenges Science councils positioned within the knowledge infrastructure as "cross-cutting enablers" and actors to address bottlenecks, such as building human capacity	Interaction and "working partnerships" between knowledge users and knowledge producers critical

2009	SETI Review of CGS		
2009	SETI Review of CSIR		
2009	International strategic review of CSIR		
2010	Human and Social Dynamic in Development Grand Challenge Science Plan (Department of Science and Technology)	Mobilise the scientific community and build capacity around four thematic areas: science, technology and society; dynamics of human and social behaviour; social cohesion and identity; societal change and evolution of modern societies. The aim is the production and use of knowledge, technology and evidence to inform policy and decision-making	Requires a change in mindset and performance by the state, private sector and all of civil society, by adopting a multidisciplinary approach to research
2010	SETI Review of MRC		
2012	Ministerial Review of Science and Technology landscape (Department of Science and Technology)	Special purpose vehicles of government: Conduct R&D directly linked to government functions especially service delivery, R&D that is not optimally done in HEIs, and conduct R&D for the private sector on a client-contractor principle, at full cost-recovery Greater role in the provision of postgraduate education and skills development Relocation of "scientific and technical	Linkages between all players in a re-fashioned "quadruple-helix" of universities and public research institutes, business, government and community actors

		services" from government to science councils to improve efficiency and effectiveness	

Source: compiled by authors

The baseline SETI Review in 1998

The first review of the SETI system in 1998 was intended to lay the basis for policy implementation, change and system alignment. It provides us with insight into the state of the field at the critical point when major mandate, funding and governance changes were introduced.

At that point in time, the SETI system was described as "sophisticated and comprehensive" marked by pockets of excellence that had "a good track record in producing internationally-competitive technological innovations" (SETI 1998). Besides these pockets of excellence, and despite great potential, the reviewers found that the system as a whole was marked by inconsistencies in its structure, size, management, operational practices and performance. Problems with the research orientation of SETIs at the time included a very narrow local customer base focused on large, well established organisations, to the detriment of global networks and informal organisations; a reliance on government as a client, and a failure to optimise Intellectual Property and pursue commercial opportunities and build the required capabilities. Thus, it is evident that the scale of interaction across the system was weak.

The three imperatives were seen to operate in tension, affecting individual councils' ability to adapt and make the required strategic shifts. The drive for efficient and effective management, and the drive to respond to the new development policy agenda were seen as competing, and the pursuit of short-term commercialisation goals and income was seen to be at the expense of longer term, strategic research and innovation. Such tensions impacted on the ability and motivation of science councils to interact, beyond traditional government and private sector actors. Thus, the review pointed to a high degree of fragmentation and misalignment at that point:

Personal relationships among actors – new and old, public and private – across the NSI are not widely leveraged into systematic knowledge partnerships and strategic alliances, and there is too little inter-institutional trust.

Research to the benefit of and in interaction with those who had been excluded from the knowledge system was virtually non-existent:

> […] linkage of public SETIs to smaller scale, less technically- sophisticated national users, clients and stakeholders – small-scale mining, small business, resource poor farmers and so forth – is still in its infancy, and often the SETI-small client interface to help articulate demand for applied science and technology is missing. There is little awareness of the competitive edge that might eventually be afforded by developing – in conjunction with these newer users – the mechanisms for innovative design, packaging […] and delivery of knowledge-intensive products, processes and services.

The review thus proposed to change the SETI system to become more responsive, efficient, accountable and transparent. Table 2.3 describes the kind of research SETIs were mandated to conduct, and the mix of core funding from the parliamentary grant and from external sources proposed for each. Almost all of these activities and modalities would drive greater interaction with external partners.

Table 2.3: SET Function/Activities and Modalities

SET function/activity	**Modality**
Public interest knowledge and information dissemination	Funded through the parliamentary grant
Core research infrastructure	Where such infrastructure cannot be funded through external contract, funded through the parliamentary grant
Human resource development	Funded through parliamentary grants, usually via the agency function, or in-house
Pre-competitive research	Could be contracted out, funded via core parliamentary grants or via competitive mechanisms , but contribution from interested economic actors required
Public purpose technology development and	In strategically defined/prioritised areas, such

diffusion	research should be funded via parliamentary grants or competitive mechanisms
Research, consultancy, services or products	Contracts to meet well-defined, short-term objectives of individual government departments, funded via department budgets

Source: SETI Review 1998

In sum, the observations of the 1998 SETI Review provide a baseline from which to assess the current patterns of interaction and interactive capabilities of science councils. SETIs were encouraged to pursue interaction and cooperation across the national system of innovation and globally, to shift current practices of fragmented, closed systems with a lack of cross-disciplinary approaches, linear models of research and development and lack of awareness of the contribution of science councils on the part of communities, private sector, higher education organisations and other science councils. The complex multiple roles of SETIS, and the nature and scope of the interaction that funding would drive - between SETIs, government, private sector and in the public good - was clearly set out.

A national Research and Development Strategy to realign governance and funding arrangements

In 2002, the newly formed Department of Science and Technology (DST) released the National Research and Development Strategy as a response to the increasing concern "that the NSI was not taking shape as expected" (Ministerial Review, 2012: 56). The reorientation of South Africa's science and technology missions to address the dual goals of economic growth and social development was emphasised, and hence, the significance of social and private sector partners. A concern was to promote more fundamental and strategic research in publicly funded institutions, to avoid the risk of capture by narrow short term interests in the form of consultancy, technology integration and extension.

Building on the 1998 SETI Review, the mandate of public SETIs to align with development priorities was to be effected by strengthening governments' steering role, in the setting of priorities, ensuring more effective functioning and strong oversight over "outputs, outcomes and impacts" of higher education institutions, science councils and department based institutes.

The issue of alignment and coordination was foregrounded. The New Strategic Management Model (2004) was the mechanism intended to implement DST's cross cutting role setting common governance standards and quality assurance mechanisms. Multi-sectoral institutions like the CSIR and HSRC were to be located directly under the control of the DST. The location of some sector-specific institutions would be changed to optimise their role. It was proposed that DST should develop a uniform framework for governance and reporting on public research institutes, but that line departments would set the goals and budgets for the sector specific science councils that report to them (PMG 2009). The development of a "Science and Technology Budget" was proposed to facilitate more effective integration and coherence, to enable DST to advise Treasury, the Cabinet and Parliament on the national system. Thus, line departments would have a greater oversight role over their SETIs, but the Science Vote would serve an integrative function. Further, it was acknowledged that an increase in core funding was required, to enable science councils to reorient to national priorities and readjust the balance of funding - and hence, strategic and contract research - across their portfolios.

Performance management to drive change in science councils

A Balanced Scorecard framework based on Key Performance Areas was introduced after the 1998 SETI review to shape the activities of individual scientists and the institutional compact with their line departments. The concern was to create organisational efficiency and effectiveness (Adam, 2002). A review of the 2001/2 performance indicators used by each council informed a comprehensive performance management system to promote change (DST 2003). Analysis of the activities that were to be promoted provides insight into the ways in which science councils were expected to change, and the mechanisms intended to promote greater interaction across the public research system.

The key concept employed in the balanced scorecard framework was that of a "stakeholder perspective". KPAs assessed "technology diffusion/dissemination of information and research results" and the "promotion of networks and linkages" as key objectives. The shift toward greater commercialisation made sustainability and financial indicators essential, as were efficiency indicators. Indicators also included science councils' roles in growing and transforming the "knowledge stock" for science, and contributing to scientific output.

During the 2000s, most of the funding, incentive and support mechanisms proposed and initiated in terms of the National R&D Strategy focused on promoting science council interaction with and to the benefit of the private sector (the Innovation Fund, THRIP, SPII, GODISA incubator, Technology Stations). Most of the linkages supported financially aimed to promote technological cooperation, technology transfer and diffusion in formal industrial sectors, and in relation to global competitiveness.

A reassertion of the technology and innovation mandate

In 2007, the OECD conducted a review of the national innovation system to make recommendations to DST on how it could be strengthened and improved (OECD, 2007: 17).

While there was little specific focus on science councils, the report highlighted how the first two mandates – contribution to science and innovation for the formal sector – had been emphasised at the expense of the inclusive social development mandate:

They provide R&D and technology transfer services that have more direct industrial application, typically helping companies move a little beyond what their internal capabilities would otherwise permit, reducing the risks and increasing the rate of innovation (2007: 112).

A major implementation problem highlighted was the 'thinness' of spread of financial resources across the system and its impact on programmes and incentive mechanisms. Although the need for concentration and consolidation of activities to achieve more effective scale had been acknowledged in the 2003 SETI review, the wide range of activities remained unchanged at the time of the OECD review – but the income stream had remained constant. The effect of this was to cast doubt over the ability of some units to:

> [...] continue to reach the critical thresholds needed to achieve the intended array of high quality contributions to the science base as well as major innovation impacts in firms and industries (2007: 133).

Unlike common practice in OECD countries, less institutional differentiation and specialisation was observed between South African science councils, particularly in agencies responsible for both supporting and performing research and innovation.

Grand Challenges: science councils as cross-cutting enablers

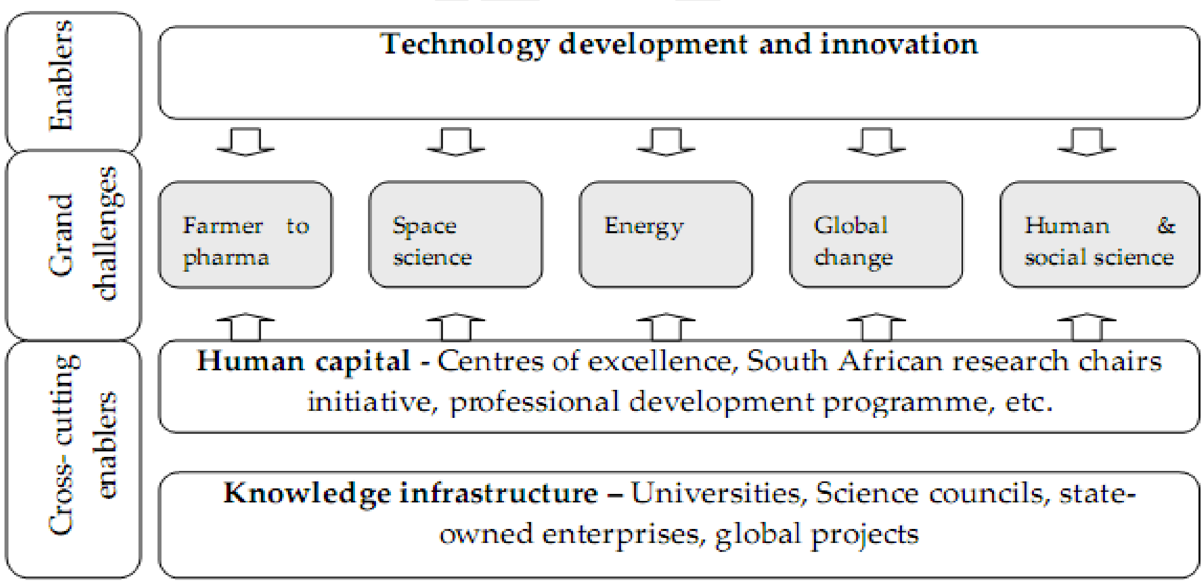
DST's response to the recommendations of the OECD review was the elaboration of a 'Ten Year Plan for Innovation', to give effect to South Africa's shift towards a knowledge-based economy

(2008). The language and discourse shifted, but essentially, the plan represented an attempt to address more directly the contextually specific challenges, gaps and bottlenecks in coordination and capacity.

Interaction and "working partnerships" between knowledge users and knowledge producers were foregrounded as a critical priority:

> Government's starting point is that the members of the public are not merely passive recipients of science and technology, but are important players in processes that shape the focus and patterns of science, technology and development (2008: 23).

The Plan adopted a new global trend to promote coherence and coordinate effort, here around five 'Grand Challenges' set out in Figure 2.1 below. Science councils were positioned within the knowledge infrastructure as "cross-cutting enablers" and actors to address bottlenecks, such as building human capacity. The Ten Year Plan thus reinforced the policy drivers of interaction and focused them in priority areas.



Source: DST, Innovation Towards a Knowledge-based Economy, p.11

Figure 2.1: Grand challenges and enablers of the Ten Year Plan

The system remains fragmented and uncoordinated: the Ministerial Review 2012

A second review of the science and technology landscape was commissioned by the Minister of Science and Technology in 2012. The review claimed that although the notion of the national innovation system was entrenched, the role of research and innovation in achieving development priorities was not coherent across government, leading to persistent fragmentation along both vertical and horizontal lines of organisation (2012: 16)

Science councils, in particular, were seen as exemplars of this incoherence, fragmentation and lack of coordination – the main criticism expressed in the 1998 SETI Review, at the beginning of the NSI change process. The reviewers acknowledged that while science councils' location within the NSI between what they called "strategic autonomy" and "government laboratory" does create organisational and accountability problems, the situation is further complicated as their "mandates [are] periodically renewed by national legislation in the form of amendments to their respective statutes" (2012: 17).

The SETI review system itself was criticised as inadequate:

> […] unpopular, because it revives and recycles the unresolved problems, and is tending to run down because of lack of support. There appear now to be no systematic, well-founded criteria for the establishment, re-mandating or disestablishment of science councils. Mission drift is rife, and direct competition with higher education institutions for resources, staff and contracts is prevalent (2012: 17).

The science council system was presented in a rather negative light, implying that drivers of interaction had not been very successful.

Funding sources and prioritisation of socio-economic objectives

The sourcing and provision of funding is instructive to shed light on interaction across the system. The Ministerial review noted that while there has been a shift towards greater contract and private financing streams, there have been marked declines in R&D funding from local business to both universities and science councils[3], taken as evidence of their declining

[3] With the exception of agriculture and health fields.

reputations (2012: 141). However, the review highlighted that the proportion of financing for R&D activities to universities outstripped that of science councils, for a number of reasons related to universities capabilities to generate new knowledge and work in multi-disciplinary environments, to achieve economies of scale, with greater academic autonomy (2012: 47). Science council expenditure on R&D comprised 16.9% of national expenditure in 2012/13, while higher education accounted for 30.7% (DST / HSRC 2012/13).

Table 2.4 reflects the parliamentary grant allocated to each science council, as a percentage of the total allocation to public research institutes (only the five science councils in this study are reflected in the table). It reflects a declining share to the CSIR and a small but steadily growing share to the other four science councils over the period.

Table 2.4 Science council parliamentary grant 2009 – 2015

Science Councils	**FINANCIAL YEAR**							**Total**
	2009/10	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	
Agricultural Research Council	537153 (16.1%)	622266 (16.7%)	755510 (17.7%)	943026 (20.3%)	950254 (18.7%)	1069151 (19.7%)	920767 (16.5%)	**5798127 (18.1%)**
Council for Geoscience	132677 (3.9%)	169176 (4.5%)	154405 (3.6%)	223006 (4.8%)	265232 (5.2%)	297839 (5.5%)	319144 (5.7%)	**1561449 (4.8%)**

Council for Mineral Technology	161108 (4.8%)	195840 (5.2%)	196956 (4.6%)	253531 (5.4%)	291509 (5.7%)	293456 (5.4%)	340742 (6.1%))	**1733142 (5.4%)**
Council for Scientific and Industrial Research	599384 (18%)	685784 (18.4%)	687169 (16.1%)	742752 (16%)	781996 (15.4%)	825740 (15.2%)	867704 (15.5%)	**5190529 (16.2%)**
Medical Research Council	251531 (7.5%)	292769 (7.8%)	283564 (6.6%)	296840 (6.4%)	416460 (8.2%)	446331 (8.2%)	615802 (11%)	**2603297 (8.1%)**
Total funding for all science councils	**3322322**	**37159955**	**4267204**	**4630027**	**5055343**	**5414062**	**5578918**	**31983831**

Source: DST (2014)

Analysis of Science Council R&D expenditure can also provide evidence of the relative prioritisation of socio-economic objectives, reflecting the niche strengths of the different public research institutes. Table 2.5 draws on the national R&D survey 2012/13. (The data includes the National Research Foundation as a funding research council, AISA, ARC, CSIR, CGS, HSRC, MRC and Mintek). The bulk of expenditure is directed at economic development objectives (59.6%). Of note, almost the same proportion is spent on research to promote manufacturing as on plant production.

Table 2.5 Science Councils' R&D expenditure by socio-economic objectives (2012/13)

	Expenditure	Percentage of Science Council R&D expenditure
DIVISION 1: DEFENCE	**279989**	**7.0**
Defence	279989	7.0
DIVISION 2: ECONOMIC DEVELOPMENT	**2400747**	**59.6**
Plant production and plant primary products	473133	11.8
Animal production and animal primary products	287431	7.1
Mineral resources (excluding energy	213007	5.3
Energy resources	108360	2.7
Energy supply	13273	0.3
Manufacturing	400864	10.0
Construction	256024	6.4
Transport	0	0.0
Information and communication services	141494	3.5
Commercial services	25053	0.6
Economic framework	70509	1.8
Natural resources	411634	10.2
DIVISION 3: SOCIETY	**413060**	**10.3**
Health	314412	7.8
Education and Training	64941	1.6
Social development and community services	33707	0.8
DIVISION 4: ENVIRONMENT	**39169**	**1.0**
Environmental knowledge	22939	0.6

Environmental aspects of development	13665	0.3
Environmental and other aspects	2565	0.1
DIVISION 5: ADVANCEMENT OF KNOWLEDGE	**893033**	**22.2**
Natural sciences, technology and engineering	760107	18.9
Social services and humanities	132926	3.3
TOTAL	**4025998**	**100**

Source: National R&D Survey 2012/13

The current emphasis on social innovation and 'quadruple helix'

The 2012 ministerial review called for stronger linkages in a re-fashioned "quadruple-helix" of universities and public research institutes, business, government and community actors. However, there were few new conceptualisations or practices in the NSI able to realise such commitments:

> The thinking about development in poorer communities needs to ascribe much greater potential for creative and active agency within communities, rather than seeing them only as recipients of social delivery […] The full range of societal actors is needed in order to mobilise their respective resources towards releasing the collective capacity for innovation (DST 2012: 26).

The reviewers noted the absence of "brokerage capacity" to mediate between actors and support development partnerships, but the financing of social innovation was evident through "corporate philanthropy" and other "private sector interests" as well as through "social entrepreneurship".

The reviewers proposed a new SETI review to provide the basis for a process of mandate revision, which could serve to establish science councils as "special purpose vehicles of government, or of a sector of government" with a range of possible functions:

- Conducting R&D directly linked to government functions and especially service delivery, as well as R&D that is not easily or optimally done in HEIs, and conducting R&D for the private sector only on a client-contractor principle, at full cost-recovery
- Their role in the provision of postgraduate education and skills development
- The relocation of "scientific and technical services" from government to science councils

In sum, the Ministerial Review reinforced the three fold mandate, proposing that each public research institute would need to provide a plan for how to “address poverty and under-development” while “simultaneously develop mechanisms to meet client demand and effect technology transfer” (2012: 135).

A triple mandate for science councils

The analysis in this chapter therefore suggests that the third wave of formation of public research institutes, their reconfiguration and reorientation to serve the needs of a state committed to inclusive development, has been driven by a vision of knowledge producers addressing dual goals of globally competitive economic development and the development challenges of poverty, unemployment and exclusion from basic necessities such as water and energy.

The potential tension between these goals, evident in an imbalance of priorities highlighted in the 1998 SETI review, clearly remains unresolved and we may expect that it continues to shape science councils’ activities in the present. Table 2.2 highlighted how each key policy text or review report has proposed the mandate and functions of science councils, as well as the nature of interaction emphasised, or the mechanisms proposed to promote linkages.

Based on this analysis of policy shifts, a three-fold generic mandate for science councils in the South African national system of innovation in the twenty first century can be identified:

- Contribution to science and the body of knowledge, connecting South Africa to global knowledge systems
- Contribution to technology, innovation and competitiveness of the private sector, both formal and informal organisations, to promote inclusive economic growth in South Africa and global competitiveness
- Contribution to innovation of government and of communities in relation to the quality of life and to promote inclusive social development

The mission and strategy of each science council will embody a distinctive balance of these goals. Each goal will entail a differentiated emphasis on fundamental, strategic, applied or experimental research – and a mix thereof. It will also entail a distinctive mix of external partners, types of relationship and channels of interaction, with related outcomes and benefits.

In turn, the practice of scientists will reflect their individual interpretation and mediation of their science council's organisational goals.

The five chapters that follow will analyse the ways in which each science council has responded to the multiple and sometimes competing policy drivers in this shifting national and global context, by analysing the existing patterns of interaction between scientists and the full range of external social partners, and the institutional conditions that are in place to realise these mandates.

Chapter 3. The design and methodology

This chapter will describe the design and methodology of the empirical work. As it is a replication study, we refer the reader to Kruss et al (2012) for a full explication of the research design decisions. Here we present an overview of the questions guiding empirical research, the sampling of PRIs, and the main changes and adaptations to the methodology in the science council context. We provide core technical information on the academic / scientist survey dataset to support claims for the generalizability of the realised samples. Finally, we developed a fresh methodology for statistical analysis to overcome limitations of the analysis of the university dataset, and we describe this in full detail, to support the analysis of patterns at each science council in the chapters that follow.

Research design

Much research tends to map what universities and public research institutes themselves identify as their cutting edge activity, or their 'best' practice, and it does not allow one to determine how typical this is of the scale or the forms of interaction in that organisation. Such a design creates a bias, in that it leads to a tendency to over-emphasise positive activity relative to the total scale and forms of activity. It is important to gain a sense of the counterfactuals, of what those scientists who are not interacting think and do, and what they see as the constraints and obstacles, or of those scientists who interact on an occasional basis in very limited ways.

The foundation of the project is thus a methodology to map forms of interaction in diverse disciplinary fields and institutional types. Who are the most common external social partners, and how knowledge intensive are the channels of interaction? For example, are researchers most typically involved in consultancy and service activities, or are they involved in participatory research projects to develop community health interventions or to develop software adaptations for the benefit of the marginalized? What are the most typical outputs and benefits for scientists, communities and social partners, and what are the main obstacles to interaction?

The core method was a survey of a random sample of all scientists within a science council. This was complemented by qualitative case studies of the organisational policy, structures and incentive mechanisms found to promote interaction in each science council. The qualitative and quantitative datasets were triangulated to create a coherent analysis of trends and patterns in each science council, in the current national policy and global context.

Aim and research questions guiding analysis

The research project aimed to explore the role of science councils in the national system of innovation, by empirically analysing their current patterns of interaction and networking with other actors:

- To investigate the nature and functioning of science councils' institutional policy, internal structure and support mechanisms that facilitate and constrain interaction with external social partners, particularly communities
- To map the extent and ways in which science councils extend their scholarship to promote innovation to the benefit of a range of external social partners, whether firms, public sector, communities or other social organisations

The research questions guiding the data gathering and analysis in each science council are organised to explore the evidence in relation to these two aims:

1. What are the institutional conditions that promote and facilitate interaction in a science council?

a. What is the history of the science council, and what are the main changes that have taken place over time, in terms of its strategic mission, knowledge functions and role in the national system of innovation?

b. What are the conceptualisations of interaction in relation to research, innovation and interaction with external partners in the science council and how is this reflected in their strategic policy and missions?

c. What are the organizational interface structures to promote and support interaction?

d. What are the incentives for individual scientists to interact with external partners?

2. What is the scale and pattern of interaction with external social partners typically found in these condition?

a. What is the scale of interaction in general amongst scientists at the science council?

b. Who are the most common *externa*l social partners of scientists at the science council?

c. What are the types of relationship in general and associated with distinct types of partners?

d. What are the channels of interaction in general and associated with distinct types of partners?

e. What are the main benefits of interaction, in terms of outputs and outcomes?

f. What are the main constraints on interaction?

The institutional sample

There are 14 public research institutes in South Africa, under the line management of distinct government departments, with a mix of research performing and funding functions, and a general or niche focus.

Table 3.1: PRIs in South Africa

PRI	Line department	Main role
Council for Scientific and Industrial Research	Science and Technology	Research / General
Human Sciences Research Council	Science and Technology	Research / General
National Research Foundation	Science and Technology	Funding / General
Africa Institute of South Africa (incorporated into the HSRC 2013)	*Science and Technology*	*Research/ niche*
Medical Research Council	Health	Research and funding / Niche
National Health Laboratory Services	Health	Research / Niche
Agricultural Research Council	Agriculture	Research /Niche
Council for GeoScience	Minerals	Research / Niche
Council for Mineral Technology / Mintek	Minerals	Research / Niche
Water Research Commission	Water Affairs	Research and funding / Niche
South African National Energy Development Institute	Energy / DST	Research / Niche
Nuclear Energy Corporation of South Africa	Energy	Research / Niche
Marine Coastal Management	Environmental Affairs	Research / Niche

South African National Biodiversity Institution	Environmental Affairs	Research / Niche

Source: DST 2010 and authors' elaboration

The empirical focus was initially planned to be on two very diverse research performing institutions, the Council for Scientific and Industrial Research (CSIR) and the Agricultural Research Council (ARC), and one research and funding council, the Medical Research Council (MRC). The selection potentially allowed for comparison between those working in relation to key industrial sectors, and in two of the most critical fields related to human and social development as highlighted in government's priorities - health and agriculture. This would allow for a disciplinary spread and also, include distinct types of science council.

However, pragmatic considerations led to a broader selection of four research performing institutions, one general and three with a niche focus, and one research and funding science council. There were protracted negotiations and long delays around the participation of the CSIR, the largest and oldest science council. Two other PRIs were thus selected and added to the institutional sample, based on the fact that they were the next two largest. These are the Council for GeoScience (CGS), and Council for Mineral Technology (Mintek), related to geoscience and mapping, and minerals respectively. In the event, the CSIR participated in the study.

Taken together, the sample provides an excellent spread of large and small councils, of multi and mono-sectoral councils, of councils directly under the mandate of DST and those under line departments, and of councils that conduct research only and that manage and disburse grant funding as well, in a spread of disciplinary fields.

Case studies of institutional frameworks

The first dimension of the design was a qualitative study of the policies, interface structures and incentive mechanisms within each science council that support and promote interaction with external partners and innovation, in response to national policy imperatives and in particular, recommendations of the SETI reviews.

A set of interviews with senior managers, heads of units and directors was conducted. A full list of interviews conducted is provided in the References section of this report. An example of the interview schedule is included in Appendix 1. The aim of the interviews was to gain insight into the views of organisational leaders and management, on the nature of interaction and the organisational mechanisms instituted to promote responsiveness and accountability to stakeholders. Each interview was transcribed for analytical purposes.

Access to key documentary sources was critical – annual reports, strategic plans, organisational strategic plans, policy documents and websites. These provide insight into the organisational history, mission and culture within which scientists are active. SETI Reviews over the years were a key source for triangulation of internal organisational documentation and interviews. A period of time was spent in each institution, interviewing respondents and gathering documents.

The fieldwork was conducted between over an extended period, as each science council could accommodate the research team in its annual schedule of work:

- MRC – November and December 2012
- ARC – February 2013
- CGS – May 2013
- Mintek – June 2013
- CSIR – October 2013

In October and November 2014, a series of feedback and consultation workshops were scheduled at each science council. At ARC, we met with two groups: first an open invitation to all staff based in Pretoria, and second, with the executive management team during a formal meeting. At Mintek, we met with a group of senior managers and heads of divisions and units. At CGs we met with a selected group of senior managers including the CEO. At CSIR, we met with a small team that had been the contact point for the research, including an executive responsible for strategic networking. At MRC, we met with a group of senior managers and heads of units, including the CEO.

The research team presented a brief overview of the research approach, and focused on the draft analysis for that science council specifically, addressing a question oriented to be of potential benefit to their strategic planning in the current policy context: How can research and innovation managers at the science council promote innovation and interaction to wider social and economic benefit?

What became evident through these engagements was that much had changed at most of the science councils in the intervening period. At the MRC for example, almost two years had elapsed, a new CEO had been appointed and had instituted extensive strategic and organisational changes. Similarly, the ARC had been at the beginning stages of a ''turn around'' strategy at the time of the fieldwork, and had made considerable changes, for example, to its organisational structure, in the interim. The comments and contribution by the leaders and managers of the science councils on the draft analysis were mainly focused on the impact of these changes.

We could not change the design to one of longitudinal case studies, and research all of these changes systematically. However, the longitudinal lens was useful to ensure a more robust analysis, and remind us that each science council is examined as a case reflecting the changing roles of public research institutes, rather than to assess its successes or failures. The process foregrounded the complex organisational dynamic and extent of time required for science councils to respond effectively to the post-apartheid policy imperatives, and to address the concerns raised in the 1998 SETI Review.

The qualitative data provides a crucial context for interpreting each science council's data patterns and trends. It enables analysis of how a specific pattern of interaction has emerged and is facilitated or constrained, where there may be alignment, and where gaps and blockages.

A survey of scientists at the core of the methodology

The second dimension of the design, the mapping methodology developed to study interaction in universities, was used with slight adaptations.

An initial pilot study conducted selected key informant interviews at each institution, in order to decide how to adapt the survey instrument. For example, while universities debate 'community engagement' and 'social responsiveness' as imperatives, science councils may use other terms such as 'research utilization' or 'science communication' (Funke et al 2008) or 'stakeholder engagement'. In the event, the instrument changes were minimal, which facilitates comparability with the university sample. The main dimensions were retained, a few variables were added to some dimensions, a few were deleted and a few were amended, to reflect the partners and activities of the PRIs more accurately. The Likert scale was retained, as per the original research design for university-firm interaction in the US (Cohen et al), and as replicated in the research in developing countries (Albuquerque et al 2014). Based on this model, 1 was 'not at all', 2 was 'in isolated instances', 3 was 'on a moderate scale', and 4 was 'on a wide scale'. The survey instrument is included in Appendix 2.

The design centred on a telephonic survey of a large cohort of researchers across all units of each science council. The focus was to determine the ways in which an individual's scientific research is extended to the benefit of a range of external social partners. This enables comparative analysis of patterns of interaction within an institution, across PRIs in common disciplinary fields, or between PRIs.

A high total number of responses for each science council was required, to allow for meaningful analysis. It was decided to conduct a telephonic survey because of previous experience of difficulties in attaining reasonable response rates for postal or electronic surveys amongst academic and scientific populations. Previous research showed that one can expect a response rate at best of 10% in these types of survey administration. A computer-assisted telephonic instrument, a CATI tool, was adopted as a suitable technique. An overall response rate of 62% was achieved using such a CATI tool with the five universities in 2010. The aim for the present study was a 70% response rate per science council.

The success of a computer-assisted telephonic survey depends on:

- A highly focused, very short instrument
- The design of an MS ACCESS template for use by the interviewers
- An interview of not more than 10-15 minutes
- Well-trained and highly articulate telephonic interviewers
- Good monitoring of the quality of responses
- Support and 'buy-in' from management, to initiate a process to publicise the survey amongst research staff

This approach was rigorous, but costly, including the extensive effort of negotiating institutional collaboration.

To construct the population of all scientists depended on good cooperation with each science council. The implementation of the CATI tool depended on having reliable telephone contact details and names of researchers. Datasets of the telephone and email contact details and limited demographic details of the total population of research staff members in the focus year, 2012, were obtained from each participating science council[4].

An institution-wide process to 'advertise' the project and alert scientists that they may receive a call requesting a telephonic interview was undertaken. Each science council sent out emails from a senior leader, and included the request in weekly newsletters. Part of this information-sharing process included the circulation of a full-length consent form. (A brief verbal consent form was included in the CATI tool, and read to each person prior to agreement to participate, as part of the interview process.)

Realised sample and generalizability

The CATI tool administered survey was implemented very successfully at four of the science councils.

The CSIR refused to allow a telephonic survey, on the grounds that it required too much time of their staff, and that they could not allow access to the contact details of their staff under new legislation to protect personal information. After extensive negotiations lasting more than a year, it was agreed that the CSIR would collaborate provided that participation of individuals was completely voluntary. Accordingly, an online survey was conducted at CSIR, distributed by the CSIR via its internal email system.

The response rate was disappointing, exceeding our own low expectations. Only 66 scientists out of total population of 711 responded, a rate of 9.3%, meaning it was not statistically generalizable. Given the different methodology and poor response rate at CSIR, it was no valid to include this data in the total sample. Accordingly, the CSIR data is reported on and analysed only in a descriptive - and highly indicative manner. Discussions of the emergent trends with CSIR senior management suggested that the patterns reflected their experience and anecdotal evidence base quite accurately. The total population at the four science councils was 1 323

[4] Excluding the CSIR – see below

scientists. The direct refusal rate was generally low, on average 8%, but highest at MRC and lowest at Mintek (Table 3.1).

A number of the scientists should not have been included in the population list supplied. For example, they had resigned or no longer worked at the council. Others could not validly be included in the sample, as they were suspended or on maternity leave. It was impossible to reach some scientists despite numerous attempts.

Taking these instances into account, the total population size was amended to 1 232 scientists. The realised sample was 963, yielding a very high response rate of 78% (Table 3.1).

Table3.1: Summary of sample statistics

Status	**ARC**	**MRC**	**CGS**	**Mintek**	**Total**	**Valid responses**	***CSIR***
Completed	385	283	117	178	963	963	*66*
Refused	36	53	11	1	101	101	
Total Population	501	451	157	214	1323	1231	*711*
% Completed	77	63	75	83	73	78	*9.3*
% Refused	7	12	7	0.5	8	8	

Care was taken to ensure that the distribution of scientists in the realised sample was close to the pattern of the population within each science council (excluding CSIR). Table 3.2 and 3.3 respectively summarise the race and gender distribution of the sample relative to the population in each council. The numbers in brackets are percentages. It is evident that the samples are extremely well representative of the population of scientists when considered by race and gender. The samples for the four science councils are generalizable to the population and could be analysed with a high degree of confidence.

Table 3.2: Distribution of sample relative to population by race group

Sample	**Population**

Race	MRC	ARC	GSC	Mintek	MRC	ARC	GSC	Mintek
African	101(35)	163 (43)	61(52)	98(55)	172 (38)	213(43)	86(55)	118 (55)
Coloured	35(12)	15(4)	5(4)	5(3)	52 (12)	16(3)	5(3)	6 (3)
Indian	72(26)	8(2)	2(2)	20(11)	122 (27)	15(3)	5(3)	23(11)
White	74 (27)	197(51)	49(42)	56(31)	105 (23)	257(51)	61(39)	67(31)
Total	383(100)	383(100)	117(100)	179(100)	451 (100)	501 (100)	157(100)	214(100)

Table 3.3: Distribution of sample relative to population by gender

Sample					**Total Population**			
Gender	**MRC**	**ARC**	**GSC**	**Mintek**	**MRC**	**ARC**	**GSC**	**Mintek**
Male	75(27)	226 (59)	77(66)	103(58)	111 (25)	290 (58)	100(64)	123 (57)
Female	208(73)	157(41)	40(34)	76(42)	340 (75)	211 (42)	57(36)	91 (43)
Total	283(100)	383(100)	117(100)	179(100)	451(100)	501(100)	157(100)	214(100)

Table 3.4: Scale of interaction

Groups	MRC	ARC	CGS	Mintek	CSIR
Interaction with external partners	224 (80)	318 (83)	100 (85)	131 (73)	
No interaction with external partners	59(20)	65(17)	17(15)	48 (27)	
Total	283(100)	383(100)	117(100)	179 (100)	

For the CSIR we did not have a full population dataset, nor did we have demographic and rank descriptors of the total population. We used population data provided in the CSIR Annual Report 2012/13 as an indicator of the demographic spread of the population of scientists. Note that the total is 715, while the total population size provided to us was 711. Table 3.5 below reflects that the realised sample had more females and more whites than present in the total CSIR population of scientists. This sample is biased in that it is likely to reflect those who highly value interaction or who are actively committed to their role of engaging with external social partners, and hence, took the time to respond to the electronic survey. Hence, we share with CSIR data with these provisos strongly foregrounded in Chapter 4.

Table 3.5: CSIR sample and population

	2013 sample		**2012/13 Annual Report Population**	
Gender	**Realised No.**	**Realised Percentage**	**Percentage**	**No.**
Female	25	37,3	31,5	225
Male	42	62,6	68,5	490
Race	**2013 sample**		**2012/13 Annual Report Population**	
Black	23	37,3	46,9	335
White	42	62,6	53,1	380
Grand Total	67	100	100	715

Data analysis strategy

Analysis was conducted on the dataset for each science council separately, to allow for interpretation and comparison of the distinctive patterns associated with each.

The challenge for data analysis is that each dimension on the survey, such as external partners, had from 11 to 29 variables, and for each variable, a respondent could rate their interaction on a scale of 1 to 4. The challenge was thus to reduce complexity and to reveal meaningful patterns of association in the data, between partners, types of relationship and benefits.

The first step in data analysis was to aggregate the strongest trends for each dimension. This was done using the technique of a weighted average index (WAI), which provides a single score for each variable, with a maximum possible 4. This allows for a ranking of variables within the dimension, to describe the strongest trend. For example, a WAI of 3.1 for other science councils, of 2.9 for large firms and of 1.2 for SMMEs can be analysed as reflecting the significance of other knowledge partners and industry partners, as opposed to SMMEs for scientists in that science council.

However, the score of 3.1 may be realised if there are a small group of scientists who interact on a wide scale, or if there is a large group of scientists who interact on an isolated scale plus a group who interact on a moderate scale - and there are many other possible combinations. Aggregation can mask nuances of interaction. Another complication is that there may be important emergent trends that are masked. For example, if a small group of scientists have been encouraged or incentivised to partner with SMMEs to address a new organisational priority, then the score of 1.2 is a significant signal of new trends, rather than simply an indication of a lack of importance of SMME partners.

Hence, it was important for our analysis to reveal common trends, to aggregate, but also, to highlight emergent trends as well as where niche expertise drives interaction in specific ways on a small but significant scale.

For the university dataset, we conducted principal component analysis to simplify the data, and reveal strongest trends as well as minor trends that our qualitative data suggested was significant. Here we encountered a further limitation given the complexity of our data. We could simplify partners and types of relationship into factors, and then, we tested the correlation between these factors, to show which types of relationship correlated with specific types of partners.

Such analysis is significant to assess the ways in which science councils are achieving their three fold mandate of contributing to science, contributing to innovation in the private sector, and contribution to innovation for inclusive development. For example, in a science council, knowledge intensive forms of interaction such as research contracts or networks may be used with firms, but traditional forms of interaction that are not knowledge intensive, such as donations, may be used in engagements with individuals and households. Such more philanthropic forms of interactions typically do not extend knowledge to the benefit of community partners, and are not based on scientific expertise. This analysis enabled us to interpret the PRIs roles in the national system of innovation.

However, the statistical methods used, of PCA and correlations, did not provide a reliable measure of association between partners, types of relationships and outputs. We could not determine whether the association could be attributed to active interaction on the part of a few, or some interaction on the part of many. We could calculate correlations between the factors for partners and types of relationship, or partners and outputs, or types of relationship and outputs, but we could not link all three.

Hence, we worked with a statistical expert in an attempt to devise a more robust analytical plan. There were various dead-ends, such as using the WAI analysis to create new datasets of only those who interact actively (with ratings of 3 or 4), but this yielded a sample that was too small for analysis. We tried Multiple Correspondence Analysis techniques, but there were too many variables in our dataset for to yield interpretable graphs.

We finally settled on the analytic plan summarised in Table 3.6. We describe each statistical technique, how it was calculated and how to interpret it, in turn.

Table 3.6: Data analysis plan

Type of analysis	**Purpose**
Basic demographic information	Frequencies and descriptive statistics to explore the compositions of the institutional populations and samples.

Type of analysis	Purpose
Weighted Average Index (WAI) on: External social partners Types of relationships Channels of information Outputs Outcomes and benefits Obstacles and challenges Reasons for not engaging	Exploratory descriptive analysis to evaluate the aggregate importance of each variable within each of the seven dimensions.
Correspondence Analysis on: Partners and types of relationships Types of relationships and outputs/outcomes	To reduce complexity of variables and identify main patterns of association between partners and types of relationship or types of relationship and outputs/outcomes found in a science council.
Cluster analysis on: Hierarchical clustering on partners Hierarchical clustering on types of relationship	To identify patterns in terms of clusters of partners or relationships or outcomes most commonly found in a science council.
Classification trees on: Types of relationship for partners Types of relationship for outputs Types of relationship for outcomes/benefits	To identify the size of the group of individuals using each form of relationship and associated with a specific partner, and so on

Correspondence analysis

Correspondence analysis was used to assess the strength of measures of association between variables, such as partners and types of relationship. Correspondence analysis is an exploratory tool, much like PCA, but it is used for categorical or nominal variables. It allows us to establish not only that there is a significant association between the two variables, but also, to explore the nature of the association, and the strongest association between categories of the variables, for example firm partners and contract relationships.

Correspondence analysis produces a table of row and column profiles, obtained by dividing each observed frequency by its row or column total. It is then possible to inspect and compare the resulting percentages, to determine stronger and weaker associations. When we have a large number of variables, such as in our survey instrument, it is difficult to undertake such an inspection to find meaningful patterns.

Hence, Correspondence Analysis is a way to represent this frequency table in a graphic form in two (or three) dimensions, by creating a correspondence map. CA is also referred to as a data reduction technique, in that it reduces the number of dimensions required to display the data. It does this by decomposing the total inertia or variability, and defining the smallest number of dimensions necessary to capture an "acceptable" amount of variability. The map makes it much easier to identify stronger and weaker associations between row categories and column categories.

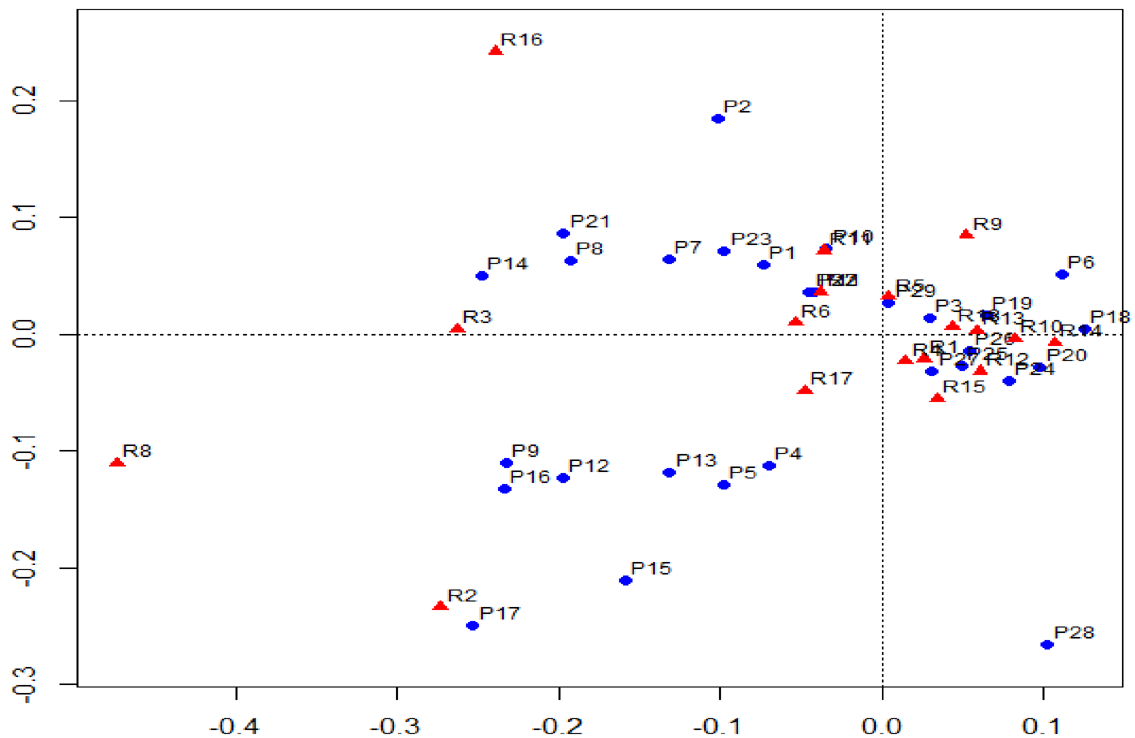
To conduct the correspondence analysis for our project, we had to restructure our likert scale data observations into a binary code. Values greater than or equal to 3 were converted to 1, and values less than 3 were converted to 0. This allowed us to generate a contingency matrix as in Table 3.7 below. Each row refers to a dimension, for example, external partners, and each column to another dimension, for example, the type of relationship. For each row, the contingency table reflects the number of 1s for that row variable, by each of the column variables.

Table 3.7: Example of a contingency matrix for correspondence analysis

	R1	R2	…
P1	# 1's for both P1 & R1	# 1's for both P1 & R2	…
P2	# 1's for both P2 & R1	# 1's for both P2 & R2	…
…	…	…	…

The correspondence map takes the form of a scatterplot, with rows and columns represented as points, and labelled appropriately (see Figure 3.1 below). The first (horizontal) axis represents the first dimension from the CA, which by definition will capture the highest amount of variability. The second (vertical) axis represents the second dimension, which will explain the second largest amount of variability.

Figure 3.1: Example Correspondence Map of partners and relationship types



We can interpret the graphs in a number of ways:

- A critical starting point is to assess the relative contribution of each dimension: the total amount of variability explained by the two dimensions; and the dimension that explains greater percentage of variability is more important for interpretation
- Points around the origin: points closest to the origin are closest to the “average”. Points in this area represent no difference, or strong homogeneity. They cannot be associated with any of the other variables. The further out the points are from the origin, the more they are different.
- Row-to-row: the distance between two points on the horizontal axis is indicative of the degree to which rows have similar profiles (in terms of the relative frequencies of the column variables).
- Column-to-column: the distance between two points on the vertical axis is indicative of the degree to which columns have similar profiles (in terms of the relative frequencies of the row variables).

- For both of these cases, the closer the points (two or more blue P circles, or two or more red R triangles in Figure 3.1), the more similar are the profiles
- Row-to-column: the distance between two points is indicative of correspondence or association between the row and column variables. Row-to-column similarity can be assessed on a single dimension or on both dimensions.
- The closer two points are (a blue P circle to a red R triangle in Figure 3.1), the greater the proportion of that column category in the row profile

This allows us to interpret the strongest association between external partners and types of relationship in a science council, represented by those points clustered around the point of origin.it allows us to identify which partners are most associated with one another, and with which types of relationships, in the activity of scientists. It allows us to identify significant niche associations, and total outliers that are not significant in the organisation.

To conduct this analysis meaningfully required triangulation with the qualitative trends analysed from documentary and interview evidence.

Cluster analysis

The next step was to dig deeper into the association between the partners (row variables) or the types of relationship (column variables).

For this purpose, we used cluster analysis, as an extension to the correspondence analysis. We performed a cluster analysis over the correspondence analysis results, in order to help identify clusters of points on the CA scatterplot. This statistical methodology was adapted from Greenacre, using the package FactoMineR as described on http://cainarchaeology.weebly.com/extension-clustering-rows-andor-columns.html.

Rows (or columns) are progressively aggregated in a way in which every successive merging produces the smallest change in the table's inertia, and this process goes on until the table is reduced to just one row "consisting of the marginal columns of the original table" (Greenacre 2007, 116, 117 fig. 15.4).

The assumption is that there are similar profiles for the rows, for example, partners, that are merged with the smallest change in the table's inertia. The process of merging can be represented graphically most effectively as a dendogram. The process of deciding on the number of clusters included in the dendogram is complex, but the package suggests the optimal cut, and we have used this statistical cut. The advantage of this methodology is that it allows us further reduce complexity, to determine which partners or which types of relationship are most commonly associated together, in a more accurate manner. This allowed us to identify the most common patterns of partners and relationships in a science council. Again, triangulation with the qualitative analysis is essential for meaningful interpretation.

Classification trees

The third statistical technique allowed us to identify significant patterns that occur on a large or a small scale, perhaps as an emergent trend or a trend on behalf of a specific research unit within the organisation

In this analysis, relationship types are clustered using hierarchical cluster analysis, and individual respondents are then assigned cluster membership based on their mean score per cluster. Each scientist is assigned to the cluster for which they have the highest mean value.

These clusters are then sequentially split using a CART classification tree, according to their responses to external partners or outputs or outcomes and benefits.

To determine where the splits or branches of the classification tree occur the Gini coefficient is used. This coefficient ideally splits the groups into smaller "more pure" groups, with less variation within, and more between. This process builds a "tree" with various branches. The analysis is constructed with the tree function from the R package "rpart". There are various methods available that enable us to select the optimal number of branches for the tree. A cost-complexity pruning method, which looks for the tree with the smallest misclassification error, was used:

- the entire sample is divided into k samples, as equal in size as possible, for example, for the partners variable
- a classification tree of a particular size (from 0 to the full tree, with no specified stopping rule) is specified and computed k times, each time leaving out one of the k sub-samples from the computation and using it as a hold-out sample to calculate a misclassification rate
- the average misclassification rate is determined, along with its standard error

We then take each of the final leaves of the classification tree produced (that is, each final point after a branch). In that leaf there may be 1 or x number of the original clusters. The proportion of responses to particular relationship types within the clusters in that leaf is then determined.

We are thus able to relate the relationship types to the responses given for external partners or outputs or outcomes and benefits.

To relate the leaves of the tree with the relationship types, we calculated a weighted mean as follows:

The tree output gives a vector (5 x 1) of proportion of subjects in this node by cluster. We weighted the with relationship type for subject j, by proportion k if subject j belongs to cluster k. Then we calculated the mean over all n subjects (j) for each relationship type (i).

At each leaf, the proportions calculated in this way are shown in a bar chart. For ease of comparison, each column was standardised, by calculating the overall mean for that column over all subjects. To interpret these bar charts, we look at the height of the bars. The longer the bar, the larger the proportion of subjects in THIS leaf that selected this type of relationship or output or outcome than overall in the whole sample.

This analysis was repeated for each group of variables separately (partners/outputs/outcomes and benefits).

Classifiers such as rank or qualification may be added to determine if certain demographic or academic attributes are associated with distinct classifications.

In Summary

The analysis was complex statistically, and in the chapters that follow, we have done our best to interpret the key trends so that complexity is reduced and meaningful patterns emerge.

Chapter 4. A critical public research institute responding to developmental challenges: the Council for Scientific and Industrial Research

Introduction

We have distilled a three-fold generic policy mandate for science councils in the South African national system of innovation in the twenty first century:

- Contribution to science and the body of knowledge, connecting South Africa to global knowledge systems
- Contribution to technology, innovation and competitiveness of the private sector, both formal and informal organisations, to promote inclusive economic growth in South Africa and global competitiveness
- Contribution to innovation of government and of communities in relation to the quality of life and to promote inclusive social development

In this chapter, we provide an analysis of the Council for Scientific and Industrial Research (CSIR), the oldest public research institute in South Africa, which historically performed and funded basic and applied research, across a number of scientific and technology fields. The CSIR is currently said to be the largest R&D research organisation in Africa and accounts for close to 10% of the entire African R&D budget. It is the largest national science council, employing some 1 580 scientists, engineers and technologists in 2012/13, which represents 65% of its total staff complement (CSIR Annual Report 2012/13) and who typically work in multidisciplinary teams.

Evidence of the interactive practices of individual scientists and operating units was limited for the CSIR, as scientist completed a voluntary online survey, in comparison to the telephonic survey completed by the other four science councils. The voluntary online completion of the survey instrument yielded a very low response rate of 9.4%, 67 individuals out of the population of 711 scientists, so that we do not have a representative sample. The sample is also likely to be very skewed, in that those who were motivated to participate are likely to value external engagement more highly. This means it is not possible to assess the scale of interaction across the CSIR. Nor is it possible to map the patterns of interaction with any degree of confidence. Hence, in this chapter, we primarily investigate the nature and functioning of the organisation's policy, internal structure and the interface mechanisms that facilitate and constrain interaction with external social partners. The chapter begins by tracing the historical development of the CSIR, in terms of the key socio-economic demands to which it responded, to identify broad shifts in its role and identity. The second section examines the CSIR's current mandate in relation to its role in the national system of innovation and its interaction with stakeholders, drawing on formal organisational documents and interviews with managers and scientific leaders, to assess how the mandate is understood and implemented in the activities of key organisational units. The financial, developmental and intellectual imperatives driving the research agenda are identified and analysed. The third section provides an overview of the organisational structure of the CSIR, new strategic external and internal interface mechanisms, and individual incentive mechanisms, focusing on how these shape choices and options as to who scientists partner with. In the fourth section, we draw on the small non-random sample to illustrate the nature of interaction.

We will show that the mandate of the CSIR was set from its earliest origins in the period of industrialisation after 1945, but has undergone distinct shift in emphasis and priorities over time. The CSIR curently faces tensions inherent in being a government research entity that contributes cutting edge science, while at the same time, operates as a business entity to commercialise its knowledge and technology products, and attempts to fulfill its 'public good' developmental mandate through technology creation and dissemination.

Historical trajectory of the CSIR

Meeting the innovation and research needs of early industrialisation processes

Chapter 2 described how, in line with global science and technology trends at that time, the CSIR emerged in the second wave of formation of public research institutes in South Africa. The need for such a public research institute was mooted as early as 1921, to address the needs of firms in the emerging local manufacturing sector. It was legislatively established in 1945, through the Scientific Research Council Act, tasked to promote industrial and scientific research. A commemorative publication fifty years later described its origins aptly:

> The CSIR was created after World War II to undertake basic and applied research in order to boost the development of the country's primary and secondary industries -

> basic research to generate knowledge, and applied research to generate technology. Funded by a government elected by a white minority, research priorities were determined to serve minority interests, and much of the benefit derived from the resulting technology for the majority was indirect or prompted by ad hoc infrastructural demands (Basson 1996: 3).

At their inception, science councils in South Africa were under direct government control. The newly formed science council could select its own research priorities, but reported on its programmes and budgets directly to parliament, through the Prime Minister. Dr Basil Schonland, who had been Scientific Advisor to then Prime Minister Jan Smuts, was appointed as the first President (Basson 1996). The organisational design for the CSIR was based on Canadian and Australian models. At the time of establishment, the CSIR had a dual mandate: to conduct multidisciplinary research and to distribute funds and grants for research. The Prime Minister at the time proposed multiple functions:

> It will itself undertake certain types of research work. It will assist research work sponsored by others. It will foster the establishment of industrial research institutes. It will encourage the training of research workers. It will act in liaison with research activities in other countries and it will provide for the collection and dissemination of information in regard to research (Basson 1996: 17).

From 1945, multidisciplinary research was conducted jointly for and with the ministries of agriculture, health, industry and with related research institutes. The CSIR received around 80% of funds from government and 20% from the private sector (Scholes et al 2008: 437). This was reflected in the nature of its research. Responding to the policy imperatives of the apartheid government from 1948, the CSIR tended to conduct research which benefitted the state and private sector elites, such as defence and military technology, minerals, and commercial agriculture.

A shift to commercialisation and financial imperatives driving the agenda

Chapter 2 highlighted the major science policy change in 1989, with the adoption of the system of Framework Autonomy to manage the statutory science councils. This shift introduced a system whereby councils could act more autonomously with regard to issues of governance, setting research priorities and overall management. Given shifts in the political landscape in the period of political transition, the discourse around science shifted to emphasise alignment of scientific priorities with national socio-economic goals. Until 1994, these goals were defined by the apartheid government. The main features of the framework system that began to drive the work of the CSIR were as follows:

- It introduced a clear delegation of authority and accountability to the Board and management of each council
- It introduced a new funding system based on the principle of baseline funding as its point of departure
- It set goals for funding to be generated through contract research

This initiated a process where increasingly, the research agenda was driven by financial imperatives and market demand.

Democratisation driving a more inclusive agenda

Post-1994, the democratic government policy for the CSIR was in line with attempts to position South Africa as an economically competitive country, and build a coherent and well aligned National System of Innovation that would attempt to solve South Africa's problems – be they in industry, agriculture, defence or basic research (White Paper 1996: 4). The CSIR received its mandate from and reported directly to, first the Department of Arts, Science, Culture and Technology, and then, the Department of Science and Technology. This policy shift foregrounded the goal of cooperation, partnerships and interaction, interpreted as the need for the CSIR to:

> …work closely – either as a partner or a client – with tertiary education institutions, other science councils, research institutions and a range of private sector organisations locally and abroad, placing the focus on quality science, skills and socio-economic improvement (www.csir.co.za).

Significantly, driven by democratisation processes after 1994, the CSIR was challenged to become more accountable and inclusive in its reach, to consider its contribution to the developmental mission of the new state:

> … the CSIR has moved away from research for mere knowledge's sake to more goal-directed research aimed at promoting technology development…In 1993 the CSIR began to adjust its research strategy to increase its focus on technology for development to meet the needs of the new South Africa, a process which is rapidly gaining momentum (Manuel in Basson 1996: xii).

The SETI Review of 1998 provided a positive assessement of the CSIR's commitment to and achievements in relation to the transformation agenda, claiming that:

> Its leadership is considered to be mission-focused, visionary, dedicated, energetic, of high technical ability and people-oriented. The national priorities for SET… are systematically and operationally incorporated into the determination of all CSIR research programmes and activities (DACST 1998: Part 2: 5).

The SETI Review nevertheless recommended a number of changes and areas for improvement. One set of recommendations related to the need to be oriented more strongly towards ''enabling technologies'' to support industry to become more internationally competitive. A second related to the need to promote a more entrepreneurial culture among CSIR staff, and to develop capacity to engage with ''customers" to define strategic priorities. A third emphasised interaction with higher education and firms in the NSI, and a fourth, that a specific focus should be international linkages and alliances to tap into global scientific networks and expertise. Significantly, it was proposed that the CSIR had the capacity to function with 30-35% core government funding, with the remainder to be earned through contracts and commercialisation.

Subsequent SETI Reviews have been treated as internal organisational documents, and the reports are not available in the public domain. Available organisational documents suggest that the SETI Review of 2009 was particularly significant in shaping the current mandate. The main criticisms of the 2009 Review appear to have shaped the current organisational imperative, to prioritise and factor the *impact* of research and technology development into the design and outcomes of all projects.

Against this broad historical periodisation, the current mandate of the CSIR, as reflected in formal organisational documentation, will be analysed in the next section.

Mandate of the CSIR

The formal statutory mandate set out in the 1988 Scientific Research Council Act continues to drive the organisation's strategic mandate and operations in the present period (CSIR Annual Report 2010/11, 2012/13):

> …through directed and particularly multi-disciplinary research and technological innovation, to foster, in the national interest and in fields which in its opinion should receive preference, industrial and scientific development, either by itself or in co-operation with principals from the private or public sectors, and thereby to contribute to the improvement of the quality of life of the people of the Republic, and to perform any other functions that may be assigned to the CSIR by or under this Act (www.csir.co.za).

Analysis suggestst that the crucial difference in the approach before and after 1994, lies in a new, more inclusive interpretation of the CSIR's contribution to improve the quality of life of ''*the people of the Republic*".

The full range of research and technology development

In line with government's call for a shift from a 'resource-based' economy to a 'knowledge-based' economy, the CSIR currently positions itself as a crossing-cutting, multidisciplinary entity in the research and development value chain (CSIR Annual Report 2010/11: 109), which distinguishes it from other higher education and private sector R&D entities. The organisation sees itself as playing a complimentary role (www.csir.co.za). While higher education institutions' research ranges from fundamental to strategic basic and applied research, industry and private sector research ranges from technology development to technology transfer and implementation. The CSIR's role, it is proposed, spans the full range, from 'fundamental research' (understanding fundamental principles) through to 'technology transfer and implementation' (impact on economy and society), but focused most strongly on 'strategic basic and applied research' (generation of new knowledge and application of existing knowledge) and 'technology development' (development of technology as process, product and service) (CSIR Annual Report 2010/11: 108). The CSIR is also concerned with the 'associated responsibilities' of developing the next generation of scientists, through training students. In this regard, it has formal agreements with key university, to govern collaboration on joint supervision of post-graduate students and further post-graduate study of CSIR staff.

Global competitiveness and service delivery

A recurring theme in CSIR documents is the contribution to cutting edge science, to advanced high technology manufacturing, to strengthen the industrial base and to grow new competitive niche sectors. Examples of research are micro-manufacturing technology, advanced polymer nanocomposite research (CSIR 2010/11), new titanium based light materials for aircraft, or an innovation new to the world, a flame lens which uses air to focus and can handle virtually unlimited power, or a number of projects that improve energy consumption and efficiency for industry (CSIR 2012/13). The defence related expertise continues (for example, the design of advanced sensors, communication systems and networks), but with the added dimension of security.

Outputs related to techonology development and transfer activities have increased over time. In 2012/13 for example, the CSIR exceeded its own targets, and was granted 35 international patents, created 33 new technology demonstrators, invested R130m in new research facilities and infrastructure, and received approximately R15m in royalty and licence income (CSIR 2013). Table 4.1 below provides a list of patents awarded in 2012/13, to reflect the range of activity, from industry to health.

Table 4.1. Patents awarded CSIR 2012/13

A Method of Switching from a Source Encoded Video Stream to a Destination Encoded Video Stream: United Kingdom
Barrier Technology: Japan
Barrier Technology: United States
Crack Sealing: EPO-European Patent Office/ France / Germany / United Kingdom/ United States
Dirfinder: Canada /Malaysia
Flagellin - Gram Positive Recombinant Protein Producing Bacteria: Australia

FliD - Production of Heterologous Proteins or Peptides: European Patent Office / France / Germany / Switzerland / United Kingdom
Hoodia Plant Extract with Improved Flavour: EPO-European
Method for Converting Aloeresin to Aloesin: France / Germany / Hong Kong / Switzerland / united Kingdom
Nano Particle Carriers For Drug Administration: Mexico / Singapore / United Kingdom
Nucleosides - 5-MU Process: EPO-European Patent Office / France / Germany / Italy/ United Kingdom
Preventative Treatment and Remission of Allergic Diseases: United States
Spherezymes - Enzyme Immobilisation: Canada / China / India
Treatment of Erectile Dysfunction and Libido Enhancement: African Regional Intellectual Property Organisation

Source: CSIR Annual Report 2012/13

A second recurring thrust evident in the current organisational literature is the way the CSIR has interpreted its mandate 'to contribute to the improvement of the quality of life of the people". Organisational documents now emphasise the potential impact of its research not only on industry, but on communities or the general population, or in the form of assistance to local government on 'service delivery'. One senior manager estimated that approximately 70% of contract income is sourced from the public sector, and the majority of that is focused on ''service delivery":

> Service delivery is all over the organisation, in all the health things, our water flagship, safety and security... If you are talking about community development and support, for example, the Built Environment unit focuses on RDP housing, on waste treatment and management, things like toilet design. We have a Natural Resources Environment unit that looks at water provision to communities, and a specific group called Enterprise Creation for Development… they have a lot of experience in how to set up community based entreprise and development projects sustainably. So based on this wealth of experience, CSIR decided they can deliver a bigger service in the country and so they are on a strong growth expansion strategy (Interview with senior manager 2, 2013).

Examples of research with direct impact on communities include a water sustainability project that focuses on processes and infrastructure to treat wastewater, the development of a mobile phone health platform for communicating health information in rural areas, the deisgn and manufacture of portable, inexpensive and disposable devices to take health samples, software to improve paved roads and the design of improved roadbulding for rural areas, or programmes to expand ICT access in rural schools. Other projects have a global reach with a general impact on the population, for example, earth observation in relation to climate change processes.

Some research is aimed at both of these goals simultaneously. For example, DST has funded the CSIR to grow the field of ''aptamer-based'' products to treat dread diseases like HIV and TB, but at the same time, expand the knowledge base and grow commercialisation opportunities (CSIR 2012/11: 32). Likewise, some projects focus on the use of technology for sustainable livelihoods and enterprise creation, by providing skills development and other support to create new enterprises in remote and rural areas, such as diamond cutting or indigenous plant products.

Finally, while the CSIR is largely driven by the imperative to make an impact on national socio-economic priorities, it has a third thrust, generating and disseminating knowledge, to contribute to the body of science. This shift is a defining feature of the post-1994 CSIR. Funke et al (2008: 31) observed:

> Due to the CSIR's *Beyond 60* initiative, which has caused the organisation to rework and reconfigure its way of doing research, the work that the CSIR is currently doing is much more focused on knowledge generation than it was previously. An increased focus has now also been placed on production of Type A (basic and strategic research) and Type B (experimental and applied) research….

This is evident in the growing quantity and quality of outputs. Academic journal publications have grown from approximately 150 in 2005/6 to some 500 in 2012/13, including publications in high impact factor journals such as Nature.

Current interpretations of the mandate

The analysis thus far reflects the formally stated mandate of the organisation. Interviews were conducted with senior executive management, to add a perspective of how the decision-makers and leadership currently interpret the organisational mandate, and the significance of interaction with external partners to the realisation of their multiptle roles and functions.

It is clear from the majority of interviewees that the organisation is currently in a “phase where we are reviewing a whole lot of things and bringing in new thinking” (Interview with senior manager 8, 2013). There was a sense of strategic reflection and planning of new initiatives to address organisational challenges.

The impact of financial drivers on the research agenda

A sense of what these challenges are can be gained from independent external analyses of the CSIR mandate. It is evident that in the first instance, these relate strongly to the potentially negative effects of the shift in the funding framework towards contract research, commercialisation and market drivers. The OECD 2007 Review of the NSI, for instance, was highly critical, claiming that because it ‘devoted considerable attention to generating contract income in the period following transformation, the work of the CSIR became increasingly short-term and service focused during the 1990s’ (OECD 2007: 80). Reflecting on the 60th anniversary of the organisation, CSIR staffers publicly criticised the shift towards external contract income, arguing that while there were positive outcomes, it served to “reduce research capacity, decrease the social return from public funds and increase the cost of research to the public sector” (Walwyn and Scholes: 2006: 239). Scholes et al (2008: 437) further argued against the negative impact of financial imperatives driving the research agenda:

> …one of the main pathologies of science councils is short-termism. Perceiving their income to be under threat, and sure only of their budget allocation for a single financial year, they do not commit to long term large projects where their advantage lies. This is mostly a self-inflicted constraint.

These authors proposed that science councils, the CSIR in particular, ought to strive for a 50/50 funding model, which would allow them to find a balance between public and private sector demands.

The high level of funding sourced from contracts is thus likely to drive the interaction with external partners, whether industry or government related. The critiques around 2008 suggest that at that stage, contract and consultancy forms of interaction predominated, which can restrict knowledge genaration and be of limited benefit to the organisation and to the national system of innovation.

Currently, the CSIR does have a renewed focus on performing contract research and development with the private sector, driven by R&D tax incentives, but equally, with the public sector. Managers interviewed accurately assessed that 'almost ¾ of our income comes from contract research that we are delivering to clients' (Interview with senior manager 6, 2013). However, they stressed that clients and funders vary from 'local, municipal, provincial, national, private, international, donors, [and] multi-nationals'.

Box 4.1 is extracted from the 2012/13 Annual Report, to provide a sense of the scale of income and the main sources of funding. The parliamentary grant for 2012/13 amounted to only 30% of total income. Income from the private sector locally and internationally accounted for slightly more than half that amount, 18% of total income. The bulk of income was from the public sector, just over 51% of total income, in line with national priorities, whether global competitiveness or related to quality of life. Binary divisions between the public and private sector clients as drivers of the CSIR's research agendas are thus not useful, and can be deceptive. Private and public sector contracts may differ in terms of their drivers and their intended beneficiaries. Public sector contracts may be driven by proactive strategies, and in the interests of public beneficiaries.

Box 4.1. CSIR income 2011/12

The total operating income of the CSIR increased by 7.5% to an amount of R2 022.8 million (2011/12: R1 881 million). Revenue growth, excluding other income, amounted to 8.6%. The **Parliamentary Grant** recognised as income in 2012/13 amounted to R594.5 million, an increase of 6.7% from the prior year's amount of R556.8 million. The CSIR's continued alignment with national strategic priorities ensured that a significant part of the contract income was received from the South African public sector. **Public sector income** amounted to R1 028 million (2011/12: R952.9 million). Income from the South African **private sector and international sector** increased by 12.6% to R361 million (2011/12: R320.5 million). The CSIR's total contract R&D income increased by 9.1% to R1 389 million (2011/12: R1 273.4 million). This includes a R50.3 million (2011/12: R55.5 million) **ring-fenced allocation** from the DST. The CSIR Group's total contract R&D income increased by 9.3% to an amount of R1 388.6 million (2011/12: R1 270 million).

The funding sources indicate that the majority of external partners are likely to be in the South African public sector. However, external partners are not necessarily the same as the funders for a project. Sometimes funders fund projects on the basis that the CSIR, or its partners, have either individually or jointly sourced funds, and the funders do not directly contribute towards the activities and outcome of projects. They might, for example, propose funds from international donors such as the World Bank and collaborate with a local university on research or projects that benefit more widely. The CSIR managers interviewed reported a wide range of partners that include the South African public sector at various levels, such as municipalities, provincial governments, national governments and parastatals like Eskom, Telko and Transnet; universities; other science councils; foreign governments through bi-literal agreements; industries; NGOs, communities; international bodies and so on.

A growing focus on impact and communities

That the CSIR attempts to benefit the people of South Africa and generally to improve the quality of life of the marginalised communities was a distinct theme emphasised by most of the senior managers, perhaps to counter the claims that it had become too market-driven:

> We look at impact in the traditional two ways, which is societal impact – how does it affect lives of people whether it be individual people – and straightforward wealth generation, building of companies, through these creating jobs….for instance, how does a technology for remediation of pit latrines affect a community, how does that have an impact on the community in terms of reducing the disease burden (Interview with senior manager 1, 2013 2013).

The Ministerial Review of the national system of innovation (DST 2012) reported that a major (self-reported) problem with with CSIR is the breadth of its mandate, and hence, fragmentation across too wide a range of activities. This is partly because decisions on what to research are driven by financial imperatives, rather than by its strategic planning and intellectual imperatives:

> The CSIR is presented with a continuing flow of compelling projects, but has no adjudicating platform to decide on competing priorities: 'we're very good at starting things, but hopeless at closing them down' (DST: 2012: 76).

A move towards strategic coordination

The organisation recognised the need for strategic coordination and focus of capacity towards fewer priorities, to achieve critical mass and greater impact. This was another distinct theme emphasised by the senior managers. Executive Directors interviewed in 2013 articulated a strong sense of the organisational mandate in terms of its broader impact, that at its core it amounts to "foster scientific and industrial development and produce quality of life improvement for the people of South Africa'' (Interview with senior manager 6, 2013) – which in turn, requires interaction. For example:

> You know *that's* CSIR's mandate and people have forgotten that… A lot of the work we do creating really good technologies or knowledge and then we sort of throw it over the fence and hope somebody picks it up, and we found …that theres a very low hit rate, you really need to work with the next phase of the value chain, with the entrepeneur or with a community, just to get the technology into the market a little bit better and then it has a much better chance of taking off. So we are focusing more on the end role…and there has to be a lot more interaction to give our technologies more of a chance (Interview with senior manager 1, 2013).

> Interaction, its part of our *mandate,* because our mandate is working partnership in collaboration with others, so its embedded in what we do (Interview with senior manager 8, 2013).

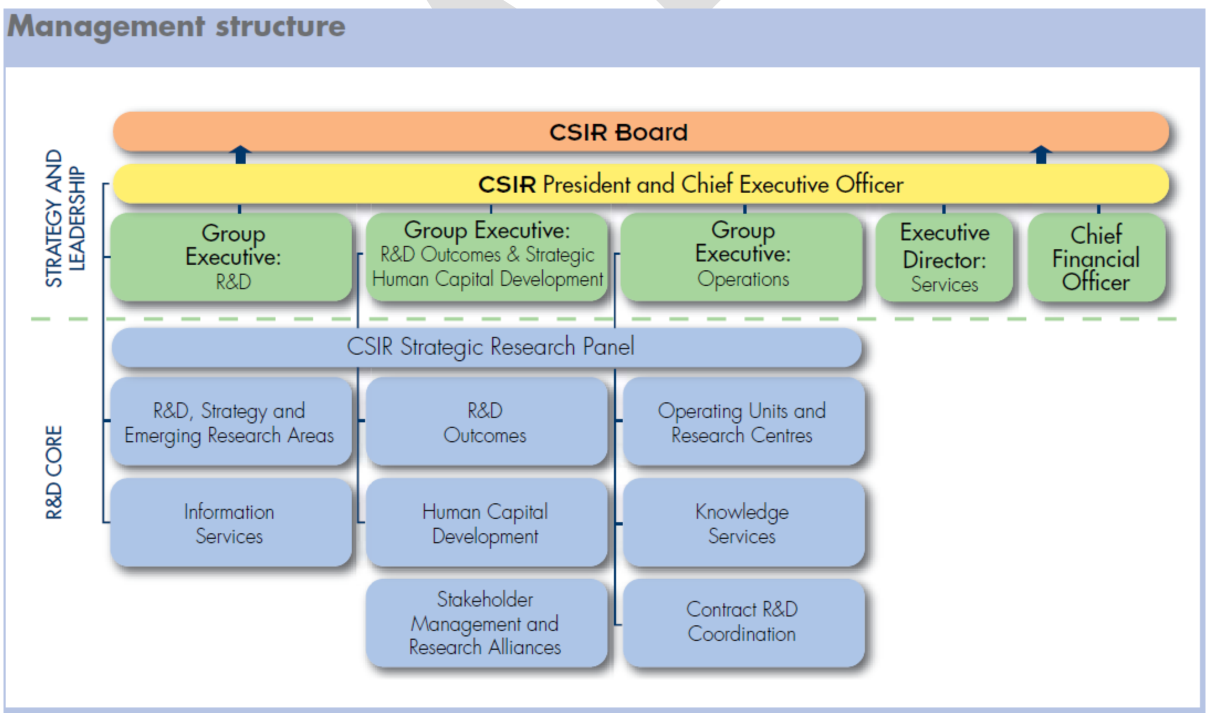
The CSIR is an extremely complex and large organisation with its mandate interpreted in diverse ways over time, and perhaps in diferent parts of the organisation. What is clearly evident is that the CSIR is currently undergoing shifts to better coordinate and balance its strategic priorities. The next section considers how this is reflected in the organisational structure, and how the structures promote and support interaction.

Aligning and focusing activity: organisational structure

One senior executive interviewed explained that the CSIR's multi-disciplinary mandate allows it to apply expertise to ''any areas that we deem necessary at any one point in time" (Interview with senior manager 5, 2013). The challenge of fragmentation and the need to align and focus activity internally is currently identified as an organisational priority. This section examines how the organisational structure and institutional culture attempted to promote critical focus and support interaction, at the time of research in 2013.

Figure 4.1 below describes the organogram in terms of formal lines of accountability, which belies the complexity of operations and internal dynamics. To zoom in to examine the contents of the box "Operating Units and Research Centres'', which contains the main research performing units. Over time, the organisation has created and evolved into eight operating business units (Biosciences; Built Environment; Defence; Peace, Safety and Security; Information and Communications Technology; Laser Technology; Material Science and Manufacturing; Natural Resources and Environment; and Space Technology). In addition to these business units, the CSIR has three Research Centres (the Meraka Institute, the National Laser Centre and the Centre for Mining Innovation). Each of these is led by an Executive Director, each is a separate budget entity, and each is required to raise funds externally in addition to their share of the parliamentary grant.

Figure 4.1. Formal organogram of CSIR lines of accountability



Source: www.csir.co.za

Over the past few years, the CSIR management has attempted to implement a new R&D Strategy that focuses its research portfolio, to achieve stronger impact. It has identified six

Research Impact Areas to coordinate and ensure that all activities are aligned with national socio-economic development priorities:

> So we selected clusters in which we focus, and the idea there is that we are looking beyond the individual organisational units, what the individual parts can do, saying, how do we pull that muscle together and address specific challenges within six very specific sectors (Interview with senior manager 5, 2013).

Table 4.2 provides a list of the six Research Impact Areas and the areas of expertise clustered to contribute to each. The idea underpinning the R&D Strategy is to maximise the impact of the business units and guide how they address the CSIR mandate:

> …we want to embed ourselves into the issues by understanding exactly the perspective of the stakeholders or the people who are facing these challenges and then saying, how do we resolve these challenges, how do we bring our multi-disciplinary capabilities to resolve these very pressing challenges of our time (Interview with senior manager 5, 2013).

Table 4.2. Research Impact Areas in the CSIR

Research impact area	**Key focus areas**
Health	• Health care delivery system • Burden of diseases: HIV, TB and malaria • Point-of-care diagnostics
Defence and security	• Information security • Interoperability and standardisation across organs of state tasked with defence and security • Command, control and coordination • Tactical and strategic situation awareness
Built environment	• Sustainable human settlements

		• Water infrastructure • Transport infrastructure • Logistics and infrastructure operations • Planning support systems
Natural environment		• Assessing and monitoring the state of the natural environment • Support for decision-making and resource planning • Technologies for water, pollution and waste solutions
Industry	Advanced manufacturing	• Titanium industry • Bio-manufacturing industry • Additive manufacturing • Microsystems and micro-manufacturing • Advanced materials and composites for industry
	Mining	• Health and safety • New mining methods • Decision support systems
Energy		• Renewable and alternative energy (under development)

Source: CSIR Annual Report 2012/13

Much was reported about this new strategic commitment. It was explained that CSIR management are attempting to change the prevailing practice of fragmentation, where operating units work in silos, despite the nature of a specific problem that may require a holistic approach across units. Multidisciplinarity is increasingly strongly encouraged, which leads quickly to interaction, collaboration and partnership, as reflected in the verbatim comments in Box 4.2 below.

Box 4.2. Multidisciplinarity driving interaction in the CSIR

I think there's a purposeful shift for us to move beyond project interactions to harnessing the CSIR multidisciplinary muscle, to offer a solution to a customer. So if a customer comes to us with a road problem we are now saying but shouldn't there also be a health element to it, shouldn't there also be an environmental element to it. So the value proposition is moving to offering a multidisciplinary solution to a client's problems.

So I think there is a move away from an arm's length relationship where "you're a customer and you just want a service from…" to "let's move towards a partnership where we understand your problem we spend time in your business, we get to know your environment, we co-develop the solution, we both have staff working on it, there's an exchange of information and expertise between the two parties, we share in intellectual property and we co-invest in the solution."

So it's no longer you have a problem and we have the answer, it's like let us, lets collaborate because our skills are complimentary, and if we have something that's missing, then let's go bring a university in or a research insittue - like if it's an agriculture problem with farmers, we don't have that expertise, let's bring in the Agricultural Research Council into this so we get that farming element.

Source: Interview with senior manager 6, 2013

These organisational shifts were driven by a new executive management team, in response to the recommendations of external reviews of the CSIR. It was thus evident that at the time of research, the CSIR was an organisation in flux, with the introduction of new centralised coordinating initiatives and processes; while within the organisational units, a different set of practices driven more strongly by the past prioritisation of financial imperatives may have tended to prevail. The next section analyses the new organisational structures and mechanisms that attempt to promote strategic alignment and support interaction, relative to the old structures and mechanisms that allowed and encouraged each business unit to set its own priorities.

Internal interface mechanisms: Research strategy, flagships, strategic partnerships and coordination structures

Centrally, an R&D Manager has the responsibility of coordinating and implementing the R&D Strategy across the operating units. One manager has the responsibility of allocation and implementation of the parliamentary grant, which requires ensuring that the infrastructure is up to date, and human capital available. This office interacts intensively with the executive directors who manage the operational units.

Typically, in an operational unit, once a research direction has been decided, a ''research advisory panel'' is set up of external science experts, to peer review the research agenda and outputs. Similarly, a Strategic Research Panel of senior scientists advises the executive management at the centralised level (see Figure 4.1). One manager reported a number of internal forums, for project management, for technology transfer, and for strategic research managers, where those responsible meet to share common interests, but there was little evidence available on the nature of their functioning and contribution (Interview with senior manager 4, 2013).

Managers interviewed reported that the focus of the busines planning cycle and reporting on progress has shifted more strongly towards the priority of ''growing impact''. The SETI Review of 2009, it was reported, highlighted the issue of impact, and in response, an impact assessment framework was designed. The next step was the recognition that ''one cannot look at impact *later* into the implementation of the programme, one has to *plan* for impact"(Interview with senior manager 8, 2013). One mechanism for this purpose is that an R&D Outcomes manager is appointed in each business unit, reporting to the executive director, and serving as an internal and external linkage point. Others reported more joint planning sessions across teams and units, at an organisational level. Managers interviewed reflected that the emphasis had shifted from a focus on outputs to outcomes and impact:

> We need to track that (impact) and be mindful of that before we finish our outputs, otherwise our outputs aren't going in the right direction. Impacts, its also a very difficult one to measure, because once it gets to true impacts your role is one of many. Its not just put in technology and that changes everything. You put in a technology and you've got to have an entrepreneur, then you've got to have a community based group…. It is

> something we are now looking more closely at, how to target it, even if we can't measure it properly (Interview with senior manager 1, 2013).

One mechanism used to facilitate multi-disciplinarity and internal coordination was competitive thematic research programmes, which only fund inter-unit collaborative projects. More recently, the mechanism of flagship programmes – ''strategic large integrated initiatives" - was initiated, in line with the R&D Strategy and the Research Impact Areas. The process begins by identifying a socio-economic problem, analysing it systematically, including interaction with stakeholders, and then the design of a multi-disciplinary research project that addresses the problem directly and in new ways, with new technologies and disciplinary perspectives. Currently there are three flagship programmes, in Health, Water, and Safety and Security, coordinated and managed by the R&D Office, a unit within the R&D Strategy and Emerging Research Areas line of accountability (Figure 4.1 above). Such initiatives attempt to shift organisational practice away from short term benefit to more sustainable and robust long term programmes.

Although there is no formal business development structure in the CSIR, increasingly, these functions are centralised, and focused on "ídentifying the strategic partners that are required in order to effect the CSIR mandate" (Interview with senior manager 6, 2013). A new centralised unit, Stakeholder Alliances and Communication (see Figure 4.1), has the responsibility to identify strategic partners, tap into the capabilities of the operating business units, and offer a multi-dsiciplinary solution to the strategic partner. Two distinct portfolios exist in this unit, one focused on research and knowledge *partners*, and the other, on *clients* within public and private entities, nationally or globally. This centralised unit thus serves as both an internal and external interface mechanism:

> We are business developers, we are the facilitators, we put in place the governance structures, the institutional modalities – so we provide the institutional context in order for them to execute R&D…. we are not monitoring project performance, but more the quality of the relationship (Interview with senior manager 6, 2013).

Strategic partners may approach the organisation through the CEO for example, who would refer the partners to this unit to create the relationship modalities. There could also be a long-standing relationship between a partner and one of the business units, but a new problem that requires accessing broader expertise from within the CSIR, and hence, the business unit becomes involved in managing the strategic relationships. Interaction with partners can thus be either 'top-down' or 'bottom-up', as reflected in Box 4.3.

Box 4.3. Initiating strategic partnerships

Strategic partnerships can come top down or bottom up, so we have examples of both for instance the DG of Health will call [the CEO] or the commissioner of police will call our office and say we want to come and talk to the CSIR about putting in place a strategic partnership so that the CSIR can support the police or so that the CSIR can support the Department of Health's national health insurance system.

And then [the CEO] will say "yes we have, we would be interested in supporting you we have the capabilities that can address your problem" and my office would then start putting in place the relationship modalities, who's going to manage the relationship, what is the content of the relationship, what are the key areas, which are the key parts of the CSIR that will contribute to this relationship and then put in place the modalities for discussion agreement. Eventually we'll have some initiatives and they will be run through the units but we will continue to oversee the relationship.

A bottom up relationship could be where the transport port authority has been working with the built environment for 20 years on ports and eventually they say "you know our problems are now we are dealing with extreme events and we need to tap into some environmental solutions or we need some modelling and decision support, to monitor what's happening in the ports and we need to tap into other parts of the CSIR''.

So that unit will come to us and say "our client is interested in accessing other parts of the CSIR - so we become involved in managing a relationship that draws on the competencies of more than one unit when there's a requirement for strategic relationship management. So that's an example where a relationship grows either from the bottom or from the top but not every relationship in the CSIR is a strategic partnership.

Source: Interview with senior manager 6, 2013

By definition, a ''strategic partnership'' is project specific, to deliver a solution to an external problem, governed by strict criteria: it is supported by executive commitment on both sides, addresses national priorities, builds new capabilities, has co-investment, a managed institutional relationship, and governance process such as a steering committee. To date, 18 strategic partnerships have been signed with national and international partners, relative to the ''thousands of clients'' the CSIR has (Interview with senior manager 6, 2013). Where such strategic partnerships are initiated from the central unit, there is a degree of internal coordination and cooperation to support all dimensions of the programme. These relationships are thus institutionalised at all levels of the organisation (Box 4.4).

Box 4.4. Strategic partnerships at the CSIR

For instance we sign a strategic partnership with Transnet and then we say we are going to plan together, so then we have to engage with the planning unit to say "what are the CSIR plans and their planning units plans for the next 5 to 10 years and what are the measures that we should put in place for this unit?" Then we have to identify areas of co-operation, and then we have to engage with the R&D unit to say "what are the R&D focus areas in the CSIR?" because we can't run off to Transnet and say "we gonna invest in nuclear programme" when there's no allocation in the R&D office for nuclear, so we have to take cognisance of what the R&D strategy is.

Then if we say we are going to share intellectual property we have to consult the IP office to advise what are the best modalities. From an ICT point of view what kind of collaboration space are we going to put in place for us and Transnet to access information outside of the firewall. So, in these forums we have those representatives that are part - so for instance the Transnet team has an IP representation from the IP office and the procurement office and the finance office and the ICT office

(Interview with senior manager 6, 2013).

However, these are very recent initiatives. Some of those interviewed claimed that the adoption of a multidisciplinary approach has not moved at the desired pace. Reasons offered are that some projects do not lend themselves to multidisciplinarity, or that researchers have numerous projects already. It was clear however, that the structure of the organisation itself and its financial model does not easily support internal collaboration. This was acknowledged and elaborated by a number of those interviewed, with exemplars in Box 4.5.

Box 4.5. Barriers to internal collaboration and networks

I think the impediment to the flow and acceptance of it [multidisciplinarity] is the measures, because at the end of the day if you're in a unit and you have to earn X amount of income per year, that's your target *and that's your budget, do you really want to give a third of the contract to the unit next door? Because it might affect your measures, your bonus?*

So the next step is to change the measure to support collaborative behaviour, and that's a bit more complex and I think that's still evolving. So I wouldn't say we are there yet, it is a difficulty because say we have this client that is interested in tapping into 3 of our units, and has to be shared among 3 units, and so we still might have some of that behaviour in the units where, like "this is my client you know, what are you doing talking to my client?" (Interview with senior manager 6, 2013).

The natural tendency is to try attract as much income into your unit as possible, because at the end of the day, when it comes to recognition and reward, we favour more the individual than the team. So parallel to this is also reviewing our career ladder programme to make sure that it does create room for collaboration and a multi-disciplinary approach (Interview with senior manager 8, 2013).

These structural, financial and logistical problems were a recurring theme throughout the interviews. One manager highlighted the absence of suitable knowledge systems as a weakness:

> Some of our systems are very good. For other information we literally have to go from office to office just to compile data and make sense of it… We should sort out our systems for interacting with the units and data gathering. I think that definitely can improve (Interview with senior manager 3, 2013).

In short, the multi-dsiciplinary partnership strategy remains a work in progress, which the prevailing institutional culture does not facilitate entirely:

> Our organisation is at the present moment designed in units that have got priorities and measures, where we are trying to go now is to say, we want to pull the muscle across the functional core areas of strength…. And that is not easy, because it involves a mind shift, it involves people required to see their role beyong their immediate job and their immediate day to day management, and the lines of management then become a little blurred. A challenge will also be how we remunerate the people, incentivise them to prioritise work beyond their individual units, that's something that we are working on (Interview with senior manager 5, 2013).

Technology transfer structures as external interface mechanisms

The Licensing and Ventures unit serves as the current manifestation of the technology transfer and commercialisation functions of the CSIR, active since the 1950s (Contract R&D management box in Figure 4.1 above). The traditional role is to licence CSIR technology, to commercialise and support start up companies based on CSIR technology. To promote the new organisational focus on impact, the aim has shifted recently so that the office is not driven solely by financial return, to select potentially lucrative projects, but equally:

> …to transfer as much technology as possible in order to maximise impacts…. That means you actually try and help as many people as you can in the organisation that have technologies. We try to help as many people external to the organisation as we can that want access to technologies, to licence technologies…Even projects that have no potential commercial returns for CSIR, *its for purely social focus* (Interview with senior manager 2, 2013, emphasis added).

The perception is that this is a global trend, and that it is based on a realistic assessment and expectation that technology transfer will never amount to a large proportion of any organisation's revenue:

> The CSIR created the South African Invention Development Cooperation in 1962, which was charged with commercialising technology of universities and science councils in the country. Now by 1964, they are telling the board: you can't expect that this is going to make money, you must look at it from the perspective of the very important role it plays in terms of facilitating the transfer or technology and knowledge to the public, to the country, because tax payers money paid for the devleopment of theose technologies and that HAS to go out (Interview with senior manager 2, 2013).

Another manager cautioned against a dichotomisation of commercial gain and social good, arguing that technology transfer involves both:

> Basically, coming up with good products that result in health, for example, to get these products to market you need a commercial partner, there's further investment required …So you either need government or NGOS to subsidise, or you have commercial parties that are investing for a return on their investment. At the same time though, if they are creating new jobs and bringing in local economic development and all of that, there's

> certainly a lot of social good. We *do* have some projects that are much more socially oriented, technology transfer that also brings a lot of social benefit (Interview with senior manager 7, 2013).

This unit thus acts as a key external interface structure for the CSIR, and is well placed to play a ‘’matchmaking role’’, both internally and externally directed. Internally, the unit works with the R&D Outcomes managers, project managers and inventors in each business unit, to evaluate technology disclosures and decide on an appropriate IP strategy. It provides support for negotiating IP terms and drafting legal contracts. It works with the notion of a range of possible ‘’impact pathways’’ that require different kinds of support. It also offers training and practical information.

The unit reports directly to senior executives, and claims strong support at senior management level for its work. A sense was gained that recently, there had been a stronger emphasis on building internal relationships and the interaction between the centralised office and business units (Interview with senior manager 7, 2013). A perception was that there was a relatively positive attitude, knowledge and awareness of IP issues, on the part of individual scientists, although there remains a degree of resistance (Interview with senior manager 7, 2013).

The unit engages proactively with potential external partners, linking them to scientists within business units. A key mechanism to achieve these goals is a dedicated web portal providing information on CSIR technologies available for licensing, and other intellectual property related issues. It has attempted to organise exhibitions and events to showcase emerging technologies and create opportunities for networking. The flagship programmes also provide a modality for coordinating organisational work with external stakeholders. A seed fund is also available for an entrepreneur in residence programme, to ‘’come in from outside and spend some time on different projects to help identify opportunities and business modesl, and potential investors and venture capital companies” (Interview with senior manager 7, 2013).

Strategic partnership unit as external interface mechanisms

The Strategic Partnership unit also plays a key role as an external interface structure. Here the value is the traction that can be gained by insertion of a project or priority into the top executive levels of decision-making and strategic organistional priorities:

> My opinion is that once you take this seriously at a higher level, things happen a bit better. So X is the Chief Representative; she is one of the Executives, Chief Representative on the Steering Committees. At that level you can see a broader picture; you can make certain commitments on behalf of the organisation and so on. So I think the level of representation is probably the key thing... Some university partners are represented by Deputy Vice-Chancellors and again, they are able to make certain commitments and provide certain support and intervene as required. So to me that is probably the key thing that has made it work (Interview with senior manager 3, 2013).

One mechanism is the hosting of consultative forums with potential stakeholders, interested parties and internal units, to faciliate strategic partnerships. Another is to join existing networks, such as the American Chamber of Commerce. More significantly, promotion of partnerships with universities and other research organisations was driven centrally, directly in response to recommendations in the 2009 SETI Review. A sub-unit facilitates interaction with universities, other science councils and research institutes, and serves as an external interface mechanism. Some relationships are centralised and include multiple units, others are at the level of a single operational unit or specific researcher. The nature of the relationship with other knowledge organisations is seen as complementary, and defined as a partnership:

> We get a lot of things [from universities] that otherwise we can't provide – so they help us train students. Our staff are visiting professors there. They lecture there. University staff serve in our committees, and so on. We do joint projects together. And the universities also use our facilities here. A lot of our staff are studying in these universities (Interview with senior manager 3, 2013).

Formal memoranda of agreement govern partnerships where there are multiple strands of interest in collaborating, across the organisation. Fifteen such cooperation agreements were reported, the most well-known being a partnership with Univeristy of Pretoria, known as the Southern African Research Alliance. A recent publication showcased research collaboration between CSIR and three universities, in 2011 and 2012, spanning co-publication, researcher exchange, scholarships, and post-graduate studies in an impressive manner (CSIR 2013). In terms of governance, these relationships around ''human capital development'' are monitored at a high level organisationally to assess progress, as they are in line with national priorities.

The CSIR is also a member of two international research alliances, but funding was reported as a constraint on their effective functioning. The Regional Research Alliance includes organisations in Botswana and Zimbabwe. The Global Research Alliance has eight partners based in Australia, US, Europe and Asia – "it is still not at the level we can be truly proud of. But the key thing is that they have competence, facilities, people who can support the work we do" (Interview with senior manager 3, 2013).

The three Research Centres have long served as highly visible external interface mechanisms, to bring in both research partners and clients. For example, Meraka's primary focus is to "contribute to enhancing equality of life and economic competitiveness in South Africa and the continent through ICT…"(www.csir.co.za). Due to the diverse and multidisciplinary nature of its research, technology development and transfer, this centre is said to be cross-cutting. The National Laser Centre (NLC) in contrast, provides a cutting edge technology platform, ''a critical core of laser technology knowledge and expertise through the research development and implementation of laser based technologies and applications in Africa and enable the South African industry to improve their competitiveness and expand their market share' (www.csir.co.za). The Centre for Mining Innovation represents a long-standing niche expertise, focused on 'research into the core business of underground mining: breaking and moving rock safely and efficiently, without harming the workers involved', in both formal and informal sectors.

Individual incentive mechanisms

The nature and role of individual incentive mechanisms at the CSIR is set in the performance management system and individual key performance areas annually. In line with the Beyond 60 Strategy, in 2006 a new system of career ladders was introducted, to develop capacity and career growth. It was noted that:

> In the past, staff members may have felt discouraged from focusing on publishing and more research related activities. In the new approach, the idea is not to penalise people for this, but rather to encourage different behaviour based on the B60 philoshophy (CSIR 2006).

It thus seems that KPAs are likely to drive publication and contribution to the scientific mandate, while interaction with external partners is an integral part of activities, driven by financial imperatives.

The individual incentive system was perceived in many different ways by managers and heads of units interviewed. It was reported that until recently, there had been an incentive scheme to encourage scientists to file patents, and there is a financial benefit sharing scheme for the creators of intellectual property successfully commercialised. Following a review of the scheme, it was decided that there should be no individual incentives or rewards. Indeed one senior manager, as did most of them, argued that the "only incentive that one can speak of now is that one has the freedom to pursue one's research". That, for many, is motivation or incentive on its own. In response to the question of incentive mechanisms, a senior manager stated:

> Until about what? Last year? End of April last year. We had KPI's relating to how many partnerships do you have with universities in particular, how many of your staff are, how many visiting people from universities came here and so on; there were about four indicators. One was on a previously disadvantaged institution. So that was a way I think of making an incentive in the sense that units have to meet that KPI. This year it was reviewed, they are not reporting on it this year. The only incentive I think that they have on our side is the opportunity for the seed funding. It is not great but for those who are interested, it's definitely an extra motivation to say "well, since I can get a bit of money for a workshop for this and that, let me do this". So that's the only, certainly direct motivation or incentive from our side that we have (Interview with senior manager 3, 2013).

Some interviewees reported that KPIs are changed periodically, making it difficult to motivate scientists. Instances were reported where a unit director created a special award for a scientist who championed a strategic multi-disciplinary partnership, but there are currently few explicit organisational incentives directly motivating individuals to facilitate particular forms of external interaction.

In the section that follows, we describe trends and examples of the nature of interaction reported by individual scientists, as they interpret and enact the shifting and complex organisational mandate in their scientific work.

Patterns of interaction with external stakeholders

Out of a total population of 711 scientists at the CSIR in 2013, a very small sample of 67 scientists responded to the electronic survey questionnaire, yielding a low response rate of 9.4%. It is likely that this sample is biased, in that those who were motivated to participate are likely to value interaction more highly. Analysis of sample demographics revealed a higher proportion of whites, and females. Further analysis reflected that most were senior scientists or managers (28 in senior researcher/research specialist positions, 11 managers [5]and 8 principle managers). Relative to the average 78% response rate for the other four science councils, this meant that the CSIR data was not statistically generalizable. There were also some issues of uneven completion which imply reliability problems, to compound the lack of representivity. It is thus not possible to assess the scale of interaction across the CSIR, nor map the patterns of interaction with statistical confidence.

However, senior managers who engaged with the dataset determined that the trends resonated with their knowledge of the organisation. It is with these provisos that we present the descriptive data trends in this section.

Survey participants were asked to provide their ''best example of a research or outreach project that engaged with external partners over the last two years''. In the evaluation of the senior managers, the examples reported represented the best practice cases of the CSIR, those that would typically be highlighted in organisational documentation and reporting. These were analysed systematically to add value and aid in the interpretation of the numerical trends.

A wide range of partners

The group of senior CSIR scientists reported a wide range of partners. Table 4.3 ranks the most frequent partners, using the Weighted Average Index (WAI): South African universities, followed by national government governments, funding agencies, South African science councils and international universities. This reinforces the significance of knowledge partners and funders, both the financial and intellectual imperatives driving interaction. Funders are key to ensure research income, but are often one of a number of partners in a network. Interaction with

[5] Note that managers were interviewed and were thus more familiar with the project and its potential value to the organisation.

international knowledge partners is also significant to the mandate to improve scientific excellence. We have noted above the structured relationships with universities around post-graduate students, and research collaboration has been incentivised by science and technology instruments. The ARC and MRC have historical roots within early research groups of the CSIR, and this is reflected in an ongoing relationship in their agriculture and health focused projects. For example, a project reported in collaboration with the MRC, Cancer Association and schools assessed the extent to which schools and primary schoolchildren are SunSmart.

Table 4.3. WAI's of external partners

		CSIR						WTotal	WAI
Social partners		**<>**	**missing**	**1**	**2**	**3**	**4**		
24	**South African universities**	65	6	1	8	24	26	193	3.3
3	**National government departments**	67	6	6	14	14	27	184	3.0
29	**Funding agencies**	66	9	9	11	17	20	162	2.8
26	**South African science councils**	66	7	1	23	23	12	164	2.8
25	**International universities**	66	9	8	20	17	12	147	2.6
18	**Large South African firms**	66	8	13	12	23	10	146	2.5
2	**Provincial government departments or agencies**	67	7	15	19	18	8	139	2.3

20	**Multi-national companies**	66	8	14	20	16	8	134	2.3
19	**Small, medium and micro enterprises**	66	8	16	19	14	9	132	2.3
1	**Local government agencies**	67	8	16	23	14	6	128	2.2
27	**International science councils**	66	8	18	23	12	5	120	2.1
10	**Non-governmental agencies (NGOs)**	66	7	26	16	13	4	113	1.9
6	**National regulatory and advisory agencies (eg NACI, CHE)**	66	8	28	15	8	7	110	1.9
8	**A specific local community**	66	8	27	17	7	7	110	1.9
11	**Development agencies (eg DBSA)**	66	7	29	14	11	5	110	1.9
7	**Individuals and households**	66	8	30	16	8	4	102	1.8
5	**Schools**	66	8	32	15	6	5	100	1.7
30a	**Other**	66	42	17	1	2	4	41	1.7
21	**Small-scale farmers (non-commercial)**	66	8	37	12	5	4	92	1.6
23	**Sectoral organisations (eg Business SA, Meat packers association)**	66	8	37	10	10	1	91	1.6
14	**Community**	66	8	35	16	5	2	90	1.6

	organizations								
4	**Clinics and health centers**	67	7	41	12	3	4	90	1.5
22	**Commercial Farmers**	66	8	39	14	2	3	85	1.5
13	**Civic associations**	66	8	44	13	0	1	74	1.3
28	**Hospitals**	66	8	49	5	3	1	72	1.2
9	**Welfare agencies (eg Child Welfare)**	66	8	51	4	1	2	70	1.2
17	**Religious organizations**	66	8	51	4	2	1	69	1.2
15	**Social movements (eg Treatment Action Campaign)**	57		50	6	0	1	66	1.2
12	**Trade unions**	66	9	49	8	0	0	65	1.1
16	**Political organizations**	66	8	54	4	0	0	62	1.1
30b	**Specify**								

Firms – large SA, multi-national, SMMEs are the next most significant set of partners, as well as provincial and local government agencies. Direct interaction with a local community of individuals and households occur in isolated to moderate instances, and is more likely to be mediated via provincial and local government, or NGOs and development agencies. As we may expect, given the mission-oriented mandates of ARC and MRC, commercial farmers and clinics and hospitals are CSIR partners in isolated instances.

Most of the best examples cited involved multiple partners, indicating that senior scientists interact in complex networks. A few examples can illustrate the kinds of complementary roles played by different kinds of partners. A project on water use in tree farming involved the Water Research Commission as funders, universities and their post-graduate students who conducted trials, commercial farmers on whose land trials were conducted, scientists from other research organisations (most likely the ARC) and consultants. A project focused on technology transfer and facilities for fashion design involved two national departments (dti; Dept of Arts and Culture) a provincial department and agency (Eastern Cape Department of Arts, Sport, Recreation & Culture; Eastern Cape Performing Arts & Culture Council), provincial and national small business development agencies (Innovate Eastern Cape; SEDA), a local municipality, a university located in the region, and local fashion designers. These examples point to the need to understand the types of relationship, as interaction with say, government partners, may take various forms.

Collaborative and contract types of relationship predominate

Table 4.4 shows that the most frequent types of relationships reported by the senior scientists are collaborative R & D projects (a high WAI of 3.4), followed by contract research, research consultancy, technology transfer, design and testing of new technologies, and monitoring evaluation and needs assessment. Collaborative R&D is more likely to be driven by the scientific mandate, while contracts and consultancy are more likely in relation to firms and government partners.

Technology transfer and design of new technologies are more likely in relation to firms. One example provided was the development of new technologies and prototypes to assist the local wool industry and mohair farmers (both commercial and communal farmers); another example is providing industry with resource efficient and cleaner production assessments and solutions; and in a similar vein, a project to improve the competitiveness of the foundry industry, funded by national government. Interaction with large firms in relation to technology development is likely to be governed by strict confidentiality agreements, and hence, few such cases were reported in the survey.

Technology transfer and design could equally be to the benefit of communities, as reflected in this best example cited:

> The CSIR has developed and piloted several appropriate technologies and guidelines to improve the quality of water in rural areas and have a profound impact on rural security and livelihoods. Researchers test the most effective, integrated deployment of

technologies and water management in order to bridge the knowledge-action gap, to link research disciplines within the CSIR which together can provide an appropriate science base to enable the provision of clean water to rural communities, to ensure the sustained and expanded impact of this action-research through effective transfer of knowledge and technologies and to identify the critical design criteria that ensure sustainability of rural water supply systems in South Africa.

Technology transfer could also be direct benefit to an enterprise, but of indirect national benefit as a project focused on the refurbishment of large safety-critical water storage tanks for ESKOM and the Koeberg Nuclear Power Station indicates. The service life of the tanks was extended and a safe process developed for maintenance without interruption to the electricity supply to customers.

M&E involves technical assessments, largely for government partners, and in relation to the quality of life related mandate. An example cited was an assessment to resolve a dispute between the contractor and project engineer on the quality of materials used in upgrading roads in a township (in a municipality that is currently at the centre of service delivery protests!). CSIR scientists were brought in as neutral parties, to provide recommendations for remedial work. Another such typical case was an assessment of the state of estuaries as part of a national biodiversity assessment, to inform government policy and action.

The next most frequent types of relationship relate to the interaction with universities around developing future scientists – education of post-graduate students, and professional education. To this end, CSIR has formal Memoranda of Understanding with selected universities. A formal research collaboration around selected research areas with the Nelson Mandela Metropolitan University between 2011 and 2013 for example, involved CSIR staff lecturing and supervising students, as extraordinary professors, well as studying themselves. NMMU staff were appointed to CSIR Advisory Panels, and students were awarded scholarships. The collaboration centred on collaborative research projects, and yielded multiple outputs (CSIR 2013). Over the longer term, collaboration with the University of Pretoria was formalised from 2001, in the form of an external interface mechanism, the Southern Education and Research Alliance, to take advantage of the proximity of the two institutions. The focus was determined by the research priorities of both organisations, and many projects reportedly contribute to socio-economic development and global competitiveness. This alliance included access to costly infrastructure and equipment

(CSIR 2011), as well as staff exchange, post-graduate studies and students. In 2011, SERA reported 98 collaborative projects, 475 publications and 8 patents arising from the collaboration over the ten year period. Such formal, structured types of relationship explain why South African universities are the most frequent partners.

Approximately a third, 23 scientists, was involved in participatory research networks on a moderate to wide scale. A flagship example is a Wireless Mesh Network Demonstrator Project, that has designed a ''community based model for developing and supporting internet infrastructure development, local skills, local ownership / enterprise development, and uptake and use of new (locally developed) technology in rural areas". Candidates were nominated by the community, and locals schools were involved alongside individuals, government, local firms and multinationals. This is a salutary reminder that MNCs may be involved in terms of corporate social responsibility imperatives, to contribute to development and quality of life. The project primarily resulted in making affordable broadband Internet available in isolated rural communities, new jobs were created in Village Operator enterprises, new South African technology was produced and national policy is being improved. The project is on-going with external partners now playing the main role in operating the project.

Joint commercialisation of new product occurred only in isolated instances for the scientists in the sample. One example described was product development of enhanced medical imaging tools, in a collaboration between CSIR, an international research institute, and technology from a newly spun-off company, as well as a university and post-graduate students.

Finally, voluntary outreach programmes occur in isolated cases, suggesting a small pocket of scientists who view interaction from a welfare lens.

Table 4.4: ***WAI's of types of relationships***

	Types of relationships	<>	**missing**	**Not at all**	**Isolated instances**	**On a moderate scale**	**On a wide scale**	**(Frequency multiply by Weight**	**Weighted average index=F*W/Frequency**

				1	**2**	**3**	**4**	**F*W**	**WAI**
15	Collaborative R & D projects	67	7	3	4	22	31	201	3.4
14	Contract research	67	6	4	8	15	34	201	3.3
12	Research consultancy	67	4	5	17	20	21	183	2.9
13	Technology transfer	67	6	10	18	16	17	162	2.7
10	Design, prototyping and testing of new technologies	67	8	11	15	17	16	156	2.6
11	Monitoring, evaluation and needs assessment	67	7	15	11	17	17	156	2.6
1	Education of post-graduate students so that they are socially responsive	68	6	16	16	14	16	154	2.5
4	Continuing education or professional development	67	5	12	22	17	11	151	2.4
6	Policy research, analysis and advice	67	8	14	20	12	13	142	2.4
17	Participatory research networks	67	8	13	23	14	9	137	2.3
5	Customised training and short courses	67	6	15	23	18	5	135	2.2

9	Design and testing of new interventions or protocols	67	6	21	17	15	8	132	2.2
16	Community-based research projects	67	9	24	15	8	11	122	2.1
18	Joint commercialisation of a new product	67	8	30	15	8	6	108	1.8
3	Collaborative curriculum design	67	8	30	17	8	4	104	1.8
7	Expert testimony	67	8	29	19	9	2	102	1.7
2	Voluntary outreach programmes	67	9	30	18	6	4	100	1.7
19 a	other	68	46	17	2	0	3	33	1.5
8	Clinical services and patient or client care	67	8	54	2	2	1	68	1.2
19 b	specify								

Scientific outputs

The five most frequent outputs reported are scientific, a pattern that may be expected given the high number of university and science council partners reported. Thereafter, the work of these senior scientists more frequently led to new process (2.1) than new products (1.8), reflecting the applied nature of their research. New processes or products could result from interaction with firm or community partners. This pattern reflects the CSIR strategic thrust of promoting scientific excellence, until approximately 2011. Thereafter, a new strategic focus on impact began to drive scientists, but it is evident, takes time to become reflected in their practice.

Table 4.5. WAI's of Outputs

	outputs	<>	missing	Not at all	Isolated instances	On a moderate scale	On a wide scale	(Frequency multiply by Weight	Weighted average index=F*W/Frequency
				1	**2**	**3**	**4**	**F*W**	**WAI**
2	Academic publications	67	5	5	5	23	29	200	3.2
4	Reports, policy documents and popular publications	67	6	5	10	17	29	192	3.1
6	Scientific collaboration	67	6	6	11	16	28	188	3.1
1	Post-graduates with relevant skills and values	67	4	6	17	22	18	178	2.8
3	Dissertations	61	0	12	11	22	16	164	2.7
10	New or improved processes (eg. Treatment protocols)	59	0	27	10	12	10	123	2.1
11	Scientific	5	0	22	20	9	8	121	2.1

	discoveries	9							
9	New or improved products (eg. Drug discovery)	59	0	34	11	7	7	105	1.8
8	Community infrastructure and facilities	67	8	39	10	3	7	96	1.6
12a	Other	67	50	14	0	0	3	26	1.5
7	Spin-off companies	67	8	42	11	4	2	84	1.4
5	Cultural artefacts	69	8	49	8	0	4	81	1.3
12b	Specify								

Organisational and scientific benefit

Table 4.6 shows the WAI of the most frequent outcomes and benefits reported by CSIR scientists from their external interaction. The most frequent outcomes are to organisational and scientific benefit, and to promote the goal of scientific excellence: scientific and institutional reputation, relevant research focus and new research projects, as well as theoretical and methodological development in a scientific field. The contribution to develop scientists is reflected in the frequency of training and skills development, and improved teaching and learning. The outcomes of benefit to firms and global competitiveness, and to the quality of life of the vulnerable are equally likely as outcomes - novel uses of technology (2.6) and improved quality of life for individuals and communities (2.5). Firm productivity (2.0), and community employment generation (1.8) are less frequent outcomes.

Table 4.6. WAI's of outcomes and benefits

Outcomes and benefits		<>	missing	Not at all	Isolated instances	On a moderate scale	On a wide scale	(Frequency multiply by Weight	Weighted average index=F*W/F
				1	**2**	**3**	**4**	**F*W**	**WAI**
17	Scientific and institutional reputation	67	7	5	11	22	22	181	3.0
16	Relevant research focus and new research projects	67	6	7	8	24	22	183	3.0
1	Public awareness and advocacy	67	8	6	18	20	15	162	2.7
18	Theoretical and methodological development in an scientific field	67	7	9	17	17	17	162	2.7
6	Training and skills development	67	8	5	20	22	12	159	2.7
2	Improved teaching and learning	67	7	6	20	23	11	159	2.7

10	Novel uses of technology	67	7	13	15	18	14	153	2.6
11	Improved quality of life for individuals and communities	67	8	16	13	14	16	148	2.5
19	Cross-disciplinary knowledge production to deal with multi-faceted social problems	67	10	12	20	17	8	135	2.4
5	Intervention plans and guidelines	67	8	17	14	18	10	139	2.4
15	Participatory research processes	67	8	15	18	18	8	137	2.3
4	Policy interventions	67	8	19	13	17	10	136	2.3
12	Regional development	67	9	24	14	15	5	117	2.0
9	Firm productivity and competitivenes s	67	8	25	16	12	6	117	2.0
14	Incorporation of indigenous knowledge	67	9	28	16	9	5	107	1.8

7	Community employment generation	67	9	31	14	7	6	104	1.8
3	Community-based campaigns	67	9	29	20	5	4	100	1.7
13	Community empowerment and agency	67	9	32	14	8	4	100	1.7
8	Firm employment generation	67	9	35	12	6	5	97	1.7
20a	Other	67	49	15	0	0	3	27	1.5

Conclusion: A critical knowledge and technology institution responding to developmental challenges

The CSIR shifted from an organisation directly reporting to government, to an autonomous organisation raising funds through contract income from the private sector and commercialisation, to a complex organisation responding to national priorities and raising funds from the public and private sectors, and growing its international reputation. It plays a critical technology development and transfer role in the national system of innovation, to address goals of industry competitiveness and of inclusive social development.

However, the CSIR is grappling with the tensions inherent in being a government entity which, at the same time, has to operate not only as research institution but as a business entity and as an organisation which seeks to fulfil its 'public good' mandate. The triple mandate has been prioritised in different ways over time. At present, the emphasis is on enhancing the outcomes and impact of research and technology development in a more inclusive manner than the past, adopted to varying degrees within distinct parts of the organisation. This by definition requires a focus on partnerships, networks and interaction within the national system of innovation.

The organisational structure is characterised by a mix of business and organisational units that have long existed, that have renewed functions and that are newly created in line with current strategic priorities. The CSIR is currently attempting to achieve stronger internal coordination and alignment across its business units, which have tended to be driven by financial imperatives and their distinct disciplinary or technology interests and expertise in the past. New internal and external interface structures and mechanisms have been put in place, most notably, a R&D strategy, a central strategic coordinating unit with high level decision making powers, formal collaboration agreements with knowledge partners, and multi-disciplnary flagship programmes. These operate alongside and in collaboration with, existing internal and external interface structures such as research centres and a centralised technology transfer unit, to facilitate greater impact through strategic interaction with stakeholders.

Analysis of strongest trends in the practice of a small group of senior scientists who participated in the survey suggests that their interaction is primarily driven by scientific and financial imperatives. It is most likely to yield scientific and knowledge outputs and be of reputational benefit. There is a small cluster of interaction to the benefit of communities and social development, typically in partnership with government and firm partners, as funders. The examples cited suggest that structured external interface mechanisms support and promote much of this activty.

Chapter 5. A mission-orientation to the mining and minerals processing sector: Mintek

INTRODUCTION

Mintek is an example of a 'mission-oriented centre', a public research organization reporting to the national department of minerals and energy, responding to the needs of policymakers and actors in a specific sector. Its key role within the national system of innovation is to maximize the value derived from South Africa's mineral resources through the generation of new knowledge and novel processes. It is a small to medium science council in terms of the total number of scientists, engineers and R&D specialists. Scientists have skills in a wide range of knowledge fields, including metallurgy, chemical, electronic engineers, chemists, physicists and mineralogists. They are involved in activities from support to initial mineral investigations, ranging through to process development, design, construction and commissioning of industrial plants. The Mintek Board of Directors has a mandate to ensure that both Mintek's technical and social targets will have a meaningful impact on the present and future economy of South Africa. In line with DST's broad policy mandate for science councils, Mintek currently runs two kinds of programmes. Technical programmes are aimed at generating high economic returns for the national and regional economy, while Social programmes are aimed at skills development and educational initiatives.

This chapter begins by sketching the history of Mintek, and situating its diverse roles and activities within a brief overview of the mining value chain. Against this background, Mintek's mandate is described, and the ways in which the mandate is understood and assimilated into the institutional culture of the organization is analysed. The next section interrogates the organisational structure in the context of the strategic mandate and goals. It considers how individual units interact with each other, their strategic focus and the interface mechanisms that facilitate the present or absence of interactions with external partners. The final section maps the patterns of interaction at Mintek, highlighting how scientists interact with distinct sets of stakeholders in distinctive ways, in relation to different parts of the mining value chain.

From Minerals Research Laboratory to Mintek

Mintek was created in its present form in the third wave of establishment of public research institutes, in terms of the Mineral Technology Act (Act No. 30 of 1989). The formal mandate is to serve the national interest through research development and technology transfer, by promoting mineral technology and fostering the establishment and expansion of all industries relating to minerals processing and its products (Mintek Annual Report 2012).

Historically, the origins go way back to the establishment in 1934 of the Minerals Research Laboratory, a collaboration between the government Department of Mines, and the academic Department of Metallurgy and Assaying at the University of Witwatersrand. The aim was to assist the mining industry, at that stage the bedrock of the economy, to function and operate more efficiently and profitably. The metamorphosis to the current Mintek took varying forms, from the Government Metallurgical Laboratory in 1944, onto the National Institute of Metallurgy (NIM) in 1966, and finally, the Council for Mineral Technology created in 1981, soon to become Mintek (Jones & Curr, 2006).

At its inception in 1934, this public research institute was 100% state funded, with little financial imperative to pursue partnerships with industry. The 'framework autonomy' initiative after 1989 drove the new science council to use the Science Vote allocation to pursue public and government interests, and to follow more commercial and client-oriented directions with funding that it raised from the private sector. There is a view within the organization that the reduction of the parliamentary grant was a blessing in disguise in that "it helped the organization to think about why it was doing research" (Interview, Executive 2, June 2013), which enabled scientists to work more independently, interact with industry and to take commercial decisions.

The mining value chain in South Africa

Mining in South Africa includes the sourcing of all forms of minerals with uses in metallurgy and as energy sources, whether nuclear, coal fired or oil sourced. The value chain is complex and facilitates or requires distinct linkages in relation to upstream, horizontal and downstream processes. We borrow from Morris, Kaplinsky and Kaplan's (2012: 24) modification of Hirschman's taxonomy for linkage development, to classify interactive policy and practice at Mintek. The taxonomy requires an understanding of the nature of activities within a particular economic sector such as minerals, and then attempts to relate these activities to the main actors from a supplier or input perspective (upstream actors), process perspective (horizontal actors) and output perspective (downstream actors).

Accordingly, the first step in the minerals value chain is exploration, which can involve onshore or offshore processes. Whether it be for minerals or oil, key people and organizations involved in these process will be geologists, geophysicists, geochemists, petroleum engineers and so forth, working in minerals and energy exploration corporations such as Petro SA. Core activities would include seismic exploration, drilling and sampling for feasibility studies to determine the economic viability of future mining activities. Once a particular mining ore body is found to be economically viable, the mining process will start. The nature of activities compels Mintek to collaborate with other organizations (such as the Council for Geosciences) on the mineral exploration aspects of the mining value chain.

At the second stage of the mining value chain, Mintek's primary role starts to emerge - where processes of mineral extraction and metallurgy become crucial. For example, at Mintek's Mineral Processing Division, new innovative techniques to improve mineral extraction are developed and deployed. These technologies involve mechanisms for bringing only the valuable minerals to the surface, and to leave "gang material" at the bottom of the mine. The primary role of Mintek is applied research to improve mining techniques, the mineral extraction and metallurgical processes.

Finally, at the third stage of the value chain, Mintek is involved in the beneficiation of extracted minerals.

Given the multiple roles Mintek plays in the mining value chain, it is likely to interact with different stakeholders in upstream, horizontal and downstream activities. Potential partners upstream are large, medium, small mining companies and subsistence miners. External partners horizontal to Mintek are likely to be minerals processing and metallurgical companies who undertake similar operations but solely for commercial reasons, and without expertise in key research focus areas to improve their metallurgical practices. Downstream partners can be very diverse, including the metal industries, energy industries, paint industries, pharmaceutical industries, agricultural industries and jewelry industries.

The units and divisions of Mintek are structured to fulfill the broad strategic mandate of the organization as a science council, but reflecting these distinct stages and activities within the mining value chain, as will become apparent below.

AN ANALYSIS OF MINTEK'S ROLES AND INSTITUTIONAL CONDITIONS

Mintek's mandate and objectives

Mintek's formal strategic intent and the focus of its activities are spelled out in a 'Shareholder compact' or performance agreement between the Board of Directors and government, represented by the Minister of the Department of Mineral Resources. Box 5.1 provides an overview of the current formal agreement, and how it shapes R&D activities and offerings.

Box 5.1: Mintek's strategic objectives

Strategic intent, aligned with national priorities, includes

- maximizing the utilization of the country's finite ore resources
- the alleviation of poverty and employment creation
- value addition to mineral and metal products
- promotion of a transition from a resource-dominated economy to that which is knowledge-based

Strategic objectives:

- Enhance Mintek's visibility and credibility to all stakeholders
- Research and develop efficient mineral processing technologies and value added products and services
- Promote the mineral-based economies of rural and marginalized communities
- Uphold good governance practices
- Build world-class R&D excellence

Products and services provided:

- Fundamental research and its development financed from public, private sources, parliamentary grants, national and international sponsorships and internal reserves
- Laboratory and pilot test work, to bridge the gap between laboratory results and actual industrial processes (Shreve & Brink 1977)
- Development of innovative technologies for licensing, sale or other forms of transfer to industry
- Design and fabrication of specialized plant and equipment for the minerals industry
- Production and supply of specialized mineral and metal products
- Provision of specialized consultancy, training and advisory services to the minerals industry

Source: Mintek shareholder performance agreement for 2013/2014

What is not immediately evident is that Mintek does not only respond to national priorities, but competes in the global mineral industry. Its client base includes multi-national mining companies and governments in other countries. In a very competitive global business environment, Mintek claims competitive advantage in its

…excellent, large scale facilities, a reputation as a one-stop shop and an enormous information database developed during its 79 years of operation (Mintek Shareholder Compact 2013/14: 3).

Mintek focuses its activities on national priority commodity sectors (platinum, gold, iron, manganese and chromite ores), on energy minerals (uranium, thorium and coal), and on metals of future strategic importance (titanium, magnesium and rare earths). Key emphases include developing processing technologies that minimize environmental impact, treat damage and exploit non-viable ores; promoting downstream beneficiation and value-add products; and facilitating entry of SMMEs to the industry. Such objectives are equally shaped by current trends and priorities in the global mineral industry.

External social partners are conceived of and described as ''stakeholders''. In terms of formal commitments, the term is used repeatedly in the Shareholder Compact. For example, the mission is ''to serve our stakeholders…'' (2013/14: 1). Interviews with executives and management confirmed that ''stakeholder'' is the broad term most frequently used, to include clients, service providers, partners, collaborators as well as consultants*:*

In our case, in terms of partnerships we've got a number of different sort of, I won't call it partners, but what we would say is *stakeholders* (Interview senior manager 12, June 2013).

The term 'partners' was not frequently used, reportedly given the nature of Mintek as a public research institute funded by the state**:**

Partnerships are very, it's a few, I'm not aware of any partnerships because I mean it's a state entity, so entering into a partnership as a state… We cannot enter into partnership…. (Interview senior manager 11, June 2013).

The Shareholder compact describes Mintek's ''customer base'' as state enterprises, large MNC mining companies, junior resource companies, engineering contractors and SMMEs, both local and global. The stakeholders are thus likely to be formal, and industry related.

“Rural or marginalized communities” are identified as stakeholders in relation to which Mintek should promote mineral-based local economies, such as local jewelry, artisanal and small scale mining. In addition, there is an objective to initiate ‘’poverty alleviation programmes and support the growth of SMMEs in the mineral sector’’ (2013/14:2).

A few key terms were used to describe interaction with ‘’stakeholders’’, repeatedly mentioned by several managers, for example:

- *service provision,* typically referring to a client-service provider relationship
- *collaboration,* typically referring to a product-tailoring process for external clients
- *project management,* typically where government uses the services of a third party, with whom Mintek has the expertise of implementing projects as well as managing.

Mintek’s mandate in the national system of innovation

The formal shareholder compact sets out the current organizational mandate. Our interviews with senior executive management and heads of divisions reflect diverse trends in the way they articulated the ideal mandate for science councils as public research institutes, and interpreted the mandate for Mintek specifically.

Managers shared one common distinction – that science councils, by virtue of being government owned, should serve the state through research for the public interest of the people of the country. For Mintek specifically, this translated into the imperative,

> “to add value to South Africa’s mineral resources by research development and innovation’’ (Interview senior manager 7, June 2013).

Some managers stressed the economic imperatives and potential impact of their work primarily:

> Okay, my understanding is that the government requires of the science councils, which are really owned by the government, to do some innovative work and in our case, this will be research into the minerals industry to ensure that knowledge is generated and passed onto the industry so that South Africa actually grows economically through the mining sector (Interview senior manager 5, June 2013).

Others emphasized a dual mandate and imperative to work across all segments of the value chain, particularly to create downstream jobs and to create value through beneficiation:

> But clearly for me one of the mandates is to provide technology, to enable the mining, mineral and processing industry, to provide new technologies, to promote energy efficient, water efficient processes within the industry. You know, indirectly if you enable mining operations you will also enable job creation because if you have a deposit and it cannot be exploited there won't be jobs. It's also for us to create downstream jobs to help change the economy from a primary mining to a more knowledge based and more sophisticated economy. This is all where our contributions are. We also, one of our priorities is supporting communities in terms of things like testing for water quality (Interview senior manager 7, June 2013).

This interviewee articulated a broader focus for science councils as state agencies, to focus on addressing communities' needs in areas that are part of the government's responsibility to the public. Another manager highlighted shifts in the organisational mandate as follows:

> Now you know that over time as Mintek has evolved, our activities used to be to extract ores and …adding to the ores for our clients or for the mining companies. *Now* the question of a beneficiary came into being, now not only was it enough for us just to look at extracting those minerals, now we had to find the *uses* of those minerals (Interview Senior Manager 13, June 2013).

Some highlighted that because science councils are funded by and acting on behalf of government while also attempting to survive financially, researchers can experience a sense of being pulled between two contrasting mandates – partially for public good and partially for commercial reasons:

> So I think that's where the science councils fit in, where you have *government* who are not researchers but who are mandated to act in the interest of the public, and you have private enterprise on the other end of the spectrum who *will* do research for commercial benefit and it will be proprietary and protected research; and Mintek sits somewhere along the spectrum - and *all* science councils I think sit somewhere along the spectrum of that - to say 'yes we will do research, and we will do it for private entities who don't have the resources to do it, but we will also do research in the

> interest of the public, in the general, for the common good' (Interview Senior manager 4, June 2013).

The issue of the policy distinction and relationship between universities and science councils was a concern raised repeatedly at all levels of Mintek:

> I'd rather talk about the problems that I see in the country which I've also put forward in other forums, is that in general in South Africa we don't seem to be having definite policies of saying 'who does what for what'…We don't have a coordinated approach as a country. I always ask a question: 'what is it that we expect universities to do? What is it that we expect the science councils to do?' Is there a clear demarcation of saying '*you* as universities work up to 'this' level, beyond this level give it to the science council. You can only continue with it beyond 'this' level if the science council say 'no' they are not interested in it (Interview senior manager 4, June 2013).

The mandate of science councils as opposed to universities and firms was identified as the ability to take risk:

> ...to take on the risky kind of research that a normal business commercial orientated company couldn't do financially. So I suppose they are positioned somewhere in-between a typical university that's pretty much more the academic side of things, in between them and the market in terms of industry. So we are in a unique position in that we have a foot on either side, you know? We do the research and we interact with industry on quite a large scale. So we take the research and make sure it's applied effectively, and that's where I see the big value of science councils (Interview senior manager 8, June 2013).

The nature of research that science councils are compelled to perform as compared to what universities may be at liberty to conduct differs:

> …it's to translate, to understand the needs of industry… unless it provides benefit, it provides value. So that's where I see the science councils being able to tap in… to be able to understand what the needs *are*, where the problems *are* and then tie up on the research side (Interview senior manager 8, June 2013).

Science councils were expected to collaborate to play complementary roles, aimed at obtaining a solution to a specific problem:

> Look CSIR they are very strong; we have another unit here, we are doing a project on titanium, and there was that partnership with CSIR. So it's because they had other expertise and Mintek had the other side of it, so the two were complementing each other to solve a particular problem (Interview senior manager 11, June 2013).

At an executive level, however, there were reservations expressed regarding the distinctive roles of science councils, universities and private institutions within the system of innovation. One executive was concerned about growing mission drift:

> Look, mainly it's just something that I always say in this country, because other science councils have become universities. I think the problem in this, I think that's how, we define science councils. With science councils that's where you see a lot of innovation, not basic research. I mean the research will be done but at a certain level…So research council should be placed within 'this' space and then university should be doing your 'so called' fundamental research. So I find ourselves more as a development organisation where…those guys they take the ideas and they feed into us and then in terms of engineering we call it 'pilot', so we build from the lab to the piloting for it to be ready for bigger plants (Interview senior manager 2, June 2013).

This executive argued that the national system of innovation focuses too much on universities and the science system, and that innovation is not sufficiently demand-led.

It was evident that managers and senior scientists were working under extremely complex market conditions where they had to interact with multiple partners, with a high degree of overlap between Mintek's roles and those of universities and other science councils. For example, Mintek competes with Geoscience on certain aspects of mineralogy, and with CSIR which is purely scientific, but will also bid for certain aspects of what Mintek does. Or, because of Mintek's beneficiation strategy focused on health related issues, other councils like MRC will be there to demand a share of the market. Moreover, competitors are global, and not only national, with similar services and facilities offered in countries like Australia, Canada, Brazil, Chile, USA, China and Russia.

The managers and senior researchers interviewed thus reflect the tension in Mintek's mandate as a science council to do research that is commercial viable in a highly competitive global environment, but also to serve the interest of the public good in terms of national priorities. Mintek's research must be able to generate revenue from global and national industry through commercialization of its services and products and the issuing of licensing agreements for use of its ideas for a specific period, until such ideas are regarded as in the public domain.

A common thread in the understanding of their mandate is thus that the research done by science councils should provide solutions to identified tangible problems, whether for government or the industries or the communities which they serve. Mintek specifically has a mandate for high risk applied research and technology development with firms, but given a lack of coordination and role clarity in the NSI, as well as financial imperatives, Mintek often operates in competition with other science councils and universities.

The following section considers how Mintek is organised and the mechanisms it employs to realise its complex mandate to interact with stakeholders.

Organizational structure

The organization is under the management of a President or CEO who is supported by five Executive Managers or General Managers. There are fourteen (14) Divisional Managers that manage strategic business units.

Box 5.1 above set out the main objectives and activities and it is evident that the organizational structure of five main programmes aims to support the strategic goals and vision. Figure 5.1 below sets out the three R&D oriented divisions and the relationships between them[6]:

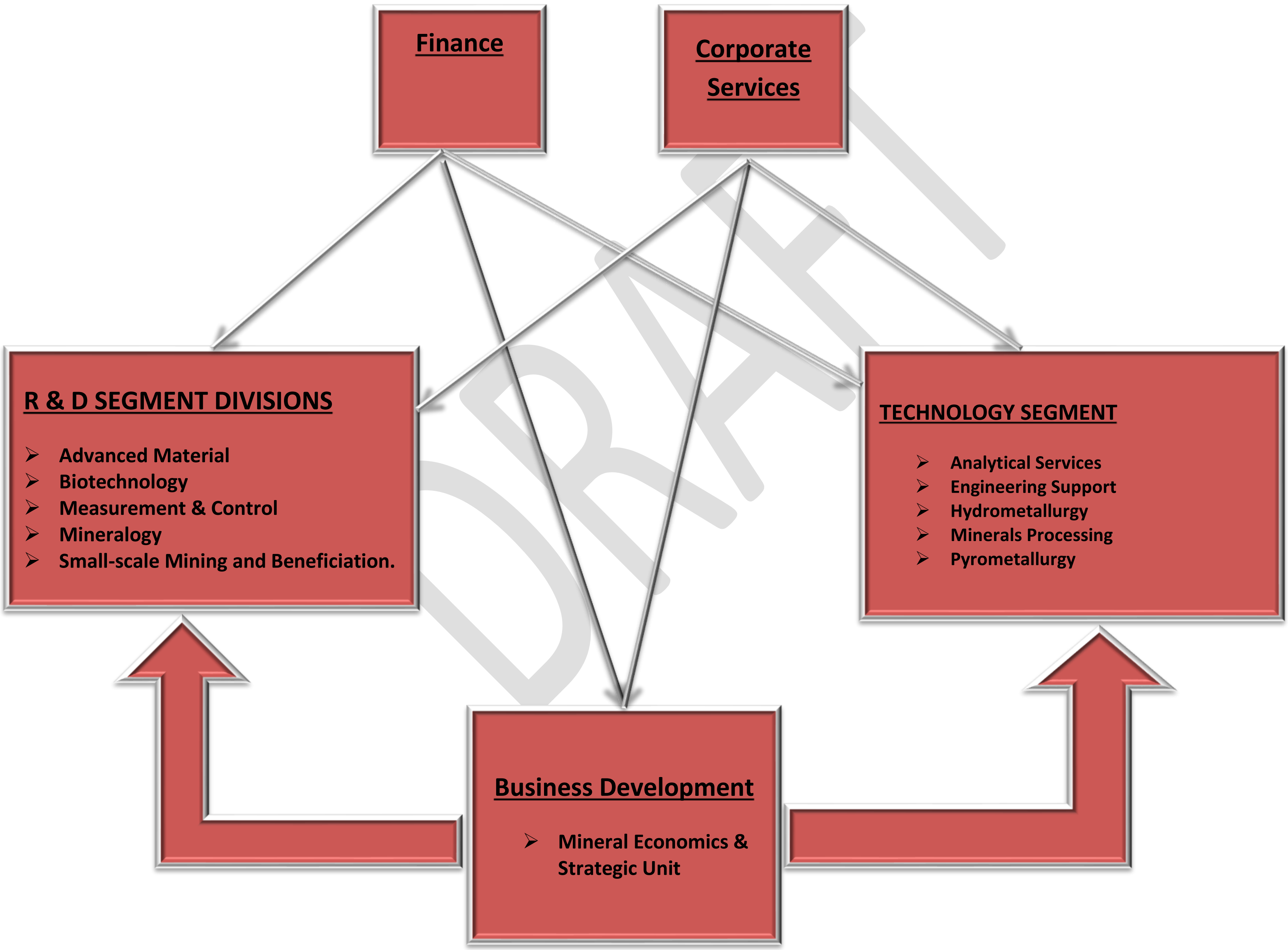
1. Technology segment division, which focuses on commercial business, with five business units

[6] Mintek had a subsidiary company called Mindev which was first registered in 2001 with the sole purpose of coordinating and facilitating joint ventures, which is now dormant (Shareholder Compact, 2013/14), and any joint ventures are developed by senior executive managers. As a result, the role of Mindev as an external interface structure is not discussed.

2. Research and Development (R &D) segment division, which focuses on research activity, with five business units

3. Business Development aimed at marketing the organization and providing support services to all Mintek business units, comprised of the Mineral Economic Strategic Unit (MESU) as well as the Technology Transfer Office (TTO)

Figure 5.1: A pictorial view of the organizations divisional segments and the lines of broad organisational support



A matrix structure

The formal business divisions in each segment are organized per field of expertise, but the organization as a whole works on a matrix system. The main operational delivery mechanism is a cluster, a multi-disciplinary team made up of team leaders from various units. Each of the clusters is led by a team leader who interacts with Line Managers across the strategic divisions. One Line Manager explained how the system works in practice:

> We have a bit of a matrix system operating within Mintek where we have the line structure where strategic business units are just sort of sitting in a line management; and then we have the technologies which get managed on a cluster basis…So I'm for example leading the base metal cluster. So everybody who wants to do anything on base metal research projects need to come to me and I basically put the whole bunch together (Interview senior manager 6, June 2013).

The clusters are formed on the basis that they are aligned to Mintek's strategic goals and that cognate units with expertise will work together to achieve organisational goals:

> Now *that* Adjudication panel will decide on *what* clusters there are, we don't chop and change them, so they've been pretty consistent for a while now. They are linked into corporate strategic thrust objectives… Now these cluster coordinators are typically your top level technical experts, specialists in Mintek that have sort of the breadth of understanding to be able to take an argument from [one unit] for a particular technology against one from another, and say "listen, you know which one is more important?" (Interview senior manager 8, June 2013).

Thus Figure 5.1 reflects that units are grouped by specific focus, and all their line managers' report to one General Manager, but there is a horizontal multi-unit interaction interface mechanism enabling collaborative research work on common commodities, as identified and agreed between the Department of Mineral Resources and Mintek. The cluster system management sits quarterly to review progress, creating a formal institutional structure to ensure that the organisation's strategic goals are manageable.

On a day-to-day basis, any of the units within a line management structure will interact together in implementation of their operational and strategic mandates.

Structures at a higher level, such as the Management Committee, ensure coordination between strategic business units in clusters:

> So we've got four realms where such things are discussed, and it's under strategic objectives. So everyone does become aware as to what the other division is doing. And also we've got the management committee [MANCOM] where those are things that will be discussed on the higher level. So if that division has an interest or see they can play a part in that arena, that's when they chip in (Interview senior manager 11, June 2013).

Line managers from different units reporting to the same general manager engage each other on the production of a particular product. For example, the Minerals Processing Division (MPD) has to engage with the Hydrometallurgical Division (HMD) on processing of minerals and HMD in turn has to forward the partially processed product to the Pyrometallurgical Division (PDD) and so forth. In addition to this, units may have coordinators to facilitate good internal communication:

> So good communication between divisions, 'us' and the other divisions is *very important* which is why we have, *within* this division we have Coordinators whose jobs it is to actually look after individual divisions … we've got one for [PDD], we've got one for [MPD] which is one of our biggest clients (Interview senior manager 5, June 2013).

The role of the coordinator is to support internal interaction and deepen communication at operational levels, lessening reliance on line managers and top-down communication:

> The effect of having a Coordinator is that *I'm* not running the meetings, *they* run the meetings, there's one person here and another person at [MPD] who arrange to have these meetings and occasionally when I have the time I will attend those meetings" (Interview senior manager 5, June 2013).

The benefit is that the line manager can focus on more strategic issues rather than operational issues. As this manager highlighted the effect of such communication within clusters on the overall outputs of the units within Mintek:

And in these meetings they discuss the details of each project and the problems associated with it, ***all*** the successes of each project, and this is where the actual interaction takes place between the divisions and you end up with a situation where processes are improved because someone takes responsibility, if a client says 'I'm not happy, this is not good. Can you fix it?'

Units can be held accountable to remedy any undesirable situations in a specific project, through internal interaction within the clusters.

It was reported that Mintek Line Managers are constantly rotated to make them familiar with all aspects of the business of the organization, which facilitates an institutional culture that makes it easy for different units to interact together. One manager highlighted the benefits of being an all-rounder within the organization, and how it facilitates the efficiency of the service to Mintek's external clients:

> So when the person talks to me I'm like 'okay, this one is there'. I told you about gold, I'm no longer working with gold, its Hydromed, I worked with mineralogy, I know what analytical science does. So anything which comes my way. Like a generalist then I can say "oh yeah, *this* is what you want, *this* is what we can do for you" then we start organising that intra-scope to solve your problems (Interview senior manager 11, June 2013).

These clusters thus operate as a critical internal interface mechanism to support interaction with external stakeholders.

Financial imperatives

Researchers reported that approximately 30% of the annual budget is funded by the State Science Vote. The remainder is funded by contract R&D, product sales and services, technology licensing agreement and joint ventures with private sector companies:

… I would say 70 % of our revenue comes out of partnerships. So what we do, we partner with private sector companies in order to streamline their processes and make them more efficient (Interview senior manager 4, 2013).

Table 5.1 reflects Mintek's income sources as reported in the Shareholder compact for 2013/14. Proportionately, 41% was forecast from the State grant allocation, an increase from the 31% share in 2012/13. Together, income generated by scientists and managers from contract research and sale of products and services is greater, 56%. The financial imperatives driving external interaction have thus been significant over the past few years.

Table 5.1: Mintek Income 2013/14 (R'000)

State grant	209569	41%
Contracted research	101741	20%
Products and services	186346	36%
Sundry income	16905	3%
Total income	514562	100

Source: Shareholders Compact

The State Grant is spread across all Mintek's operational units. The internal allocation is based on consideration of progress on projects, in line with DMR priorities and the organizational mandate. Table 5.2 illustrates the matrix system, with priority clusters linked to DMR initiatives in the vertical column, and the allocation to each strategic business unit involved along the horizontal columns.

Table 5.2: State grant allocation per cluster and business unit 2012/13

		MINTEK STRATEGIC BUSINESS UNITS													
STRATEGIC GOAL	**R&D CLUSTER**	**AMD**	**ASD**	**BIO**	**EMS**	**HMD**	**CORP**	**EXM**	**MAC**	**MESU**	**MNL**	**MPD**	**PDD**	**SSMB**	**TOTAL**
Research and develop efficient mineral processing technologies and value added products and services	**Precious Metals**		3405	2200	800	5400			4750		2975	2520	1400		23450
	Base Metals		610	2110	350	4290				650	450	230	50		8740
	Energy Minerals	50	822	3300	300	7900			700	455	1338	850	300		16015
	Mineral Beneficiation and Value addition	16714	20		340						40	1250	1620		18734
	Ferrous Minerals	1195	350		360	19556			3050	3014	165		3740		32680
Research and develop efficient mineral processing technolgies and value added products and services	**Eco-Efficiency**		355	5923	865	160			2335	700	1265	8494	6450		26547

Promote the mineral-based economies of rural and marginalised communities through technical assistance and skills development	**Small scale technology and enterprise development**	20	80								2102	5	10	15147	17364
Build world-class R&D competence	**Strategy and capacity development**						10600	36386							46986
	GRAND TOTAL	17979	5642	13533	3015	37306	20600	36386	10935	4819	8335	13349	13570	15147	190516

As an incentive for internal units, the state grant allocation is adjusted according to how effective and productive each unit is within a cluster. Interviewees in many units highlighted how allocation decisions are taken:

We've got the General Manager R&D who is responsible for it so towards the end of the year, November we do planning where we submit our proposals to him and then in December they will sit as a committee and look at how these proposals are aligned to Mintek's strategy and will they add value to Mintek and then award or approve the budget for the next financial year.

To avoid competition between units, the same process regulates the focus of each unit and how they relate to one another. This was clearly articulated by one manager:

… in the funding allocation for research projects, its not the only consideration but it is in there. You might submit a motivation and they may come back with a recommendation and say 'well look we'll only accept it provided you re-structure it in this way', for example, or 'you'd better give this part of the work to that division, and not try and do it yourself' (Interview senior manager 6 , June 2013).

The funding allocation to units, on the basis of how well they work together to achieve their individual as well as organisational goals, is thus a key internal enabling mechanism.

This organizational structure potentially allows for a degree of internal alignment between units and fosters internal interaction and collaboration between those in distinct knowledge and technology fields.

Performance Assessment

In line with science council governance, Mintek is legislatively required to submit a set of annual corporate objectives as part of its shareholder compact, and these are translated into performance indicators for external and internal reporting.

This is a critical internal interface mechanism that ensures alignment across strategic business units and provides incentives to individual scientists, in line with the organizational objectives set in terms of national priorities. In recent years, Mintek's approach to planning is informed by the Presidency's 12 National Outcomes. Appropriate objectives are identified, and these are cascaded into activities with measurable indicators. Output indicators are typical scientific indicators such as conferences, articles, reports, but also technology related outputs such as patents, technology transfers, prototypes, units of plant and equipment, value of control system sales, value of Certified Reference Material sales and so on. Significant indicators of *social involvement* identified in the latest plan that may promote and support external interaction with communities include:

- An annual Customer Satisfaction Rating Index
- Technical Assistance to DMR
- Number of new businesses created
- Percentage of people trained (in glass bead, jewellery, pottery and brickmaking, introduction to small scale mining)
- Annual Minquiz competition
- Bursaries awarded and graduates absorbed

The Performance Assessment system is a critical internal interface mechanism to promote and support interaction as part of the core function of Mintek scientists.

Dynamic interaction within clusters

Figure 5.2 depicts the dynamic interaction between the strategic business units, with square boxes representing the Technology group and oval circles the R & D group. The thin lines depict internal interaction. Activities seem to revolve around the units labelled 1, 2 and 3, those following the minerals value chain process, depicted by bold direction lines. These three units interact bi-directionally with each other, indicated by double arrows. Arrows that point in one direction suggest uni-directional interaction, with the arrowhead pointing at the unit that provides services to other units. So, for example, Unit 4 provides engineering support, interacting in a bi-directional manner. In contrast, Unit 8 focuses on process efficiency and offers services to Unit 1, 2 and 3 – and so on.

For most of the units in the Research and Development segment, the units in the Technology stream are treated as ‘clients’ that require their services, alongside external customers and clients. For example, the Advanced Materials and Minerals Processing divisions would consult Mineralogy if they need characterization of mineral ores they are not certain about.

For the Technology stream, the upstream to downstream sequence of the value chain informs the delineation of operational units. For example, one of the line managers highlighted the sequence:

> …Minerals Processing, that’s the first step because we’ve got to concentrate [in the technical sense]. So Minerals Processing department means you pre-concentrate, get rid of the ‘gang’ material…and then goes to Hydrometallurgy…when they are finished it will then go to Pyrometallurgy (Interview senior manager 11, June 2013).

For these three units, the output of one becomes the input of the other (See Figure 5.2 below). The Analytical Services Division provides analytical services to all technical divisions: “what we do is an analytical service, we would analyse *any* and *all* the samples that are generated by the other mineral processing divisions” (Interview senior manager 5, June 2013). It undertakes the stoichiometry of the mineral composition of the processed ores and thus contributes to the cost accounting of all value addition processes within Mintek. Similarly, the Mineralogy division provides analysis with respect to mineral characterisation:

> We do mineralogical characteristics of [mineral ores]. We are more a technical service division, we service other divisions. They bring their samples to us in order to determine their characteristics. Most of our clients, it will be your Mineral Processing division, Hydrometallurgy, Pyrometallurgy and [AMD] (Interview senior manager 10, June 2013).

Thus, each unit has a specific focus and is involved in the clusters for specific projects in distinct ways. For instance, the Measurement and Control (MaC) unit is distinctive in that it deals with new and existing plants where most of the prior work is completed. Once mineral ores are tested and analysed, a processing plant will need to be developed from a batch process to a fully automated plant, thus requiring steady-state process control equipment:

> Okay, we are a bit different actually to the other technical emergence of Mintek in that they typically come in at fairly early stages of a development of a project, they do a lot of test work on the ores trying to understand what the best sort of plant design *is* to optimise in order to extract the minerals from that particular ore type. We on the other hand, we deal with new plants but also existing plants and we provide predominantly processed control solutions (Interview senior manager 8, June 2013).

The Small-Scale Mining Business (SSMB) unit is the main entry point for small-scale miners and subsistence miners, focused on developmental activities rather than being strongly research based. The cluster focused on the promotion of mineral based economies of rural and marginalized communities includes AMD, ASD, MNL, MPD, PDD and SSMB as the key partners. The core activities for small-scale miners and subsistence miners entails analysis of mineral content available to determine if it is of any significant consideration:

> …but we also do get contacts through the Small-Scale Mining unit. Now Small Scale mining, what they will do is help subsistence miners, you know the guy that will go and pan for gold in the river and perhaps someone who thinks they might have a bit of a deposit on their farm and then they dig it themselves and then they want to be able to say how much of it there is. All of those people are then helped to set up proper businesses and proper production facilities through Small-scale Mining. And *when* that happens then Small Scale Mining will say to us '*here* is a project that we are working on, these people will need our assistance/answers from time to time, can you look after them?' Then we will take them and look after them (Interview senior manager 5, June 2013).

So while SSMB is the gate keeper and facilitator of such ventures, the Analytical Services Division interacts more directly with specific project stakeholders. The SSMB would do most of the ground work in formalizing external engagements and then would link internal units to a specific project, depending on the degree or nature of work required:

> So the focus of this division here was essentially to use the research funds, to use appropriate, small-scale technologies or small-scale processes to help these SMME's that will obviously want to get into the mining industry. So that's where *this* division fits into the whole of Mintek. So our sort of stakeholders are still obviously government

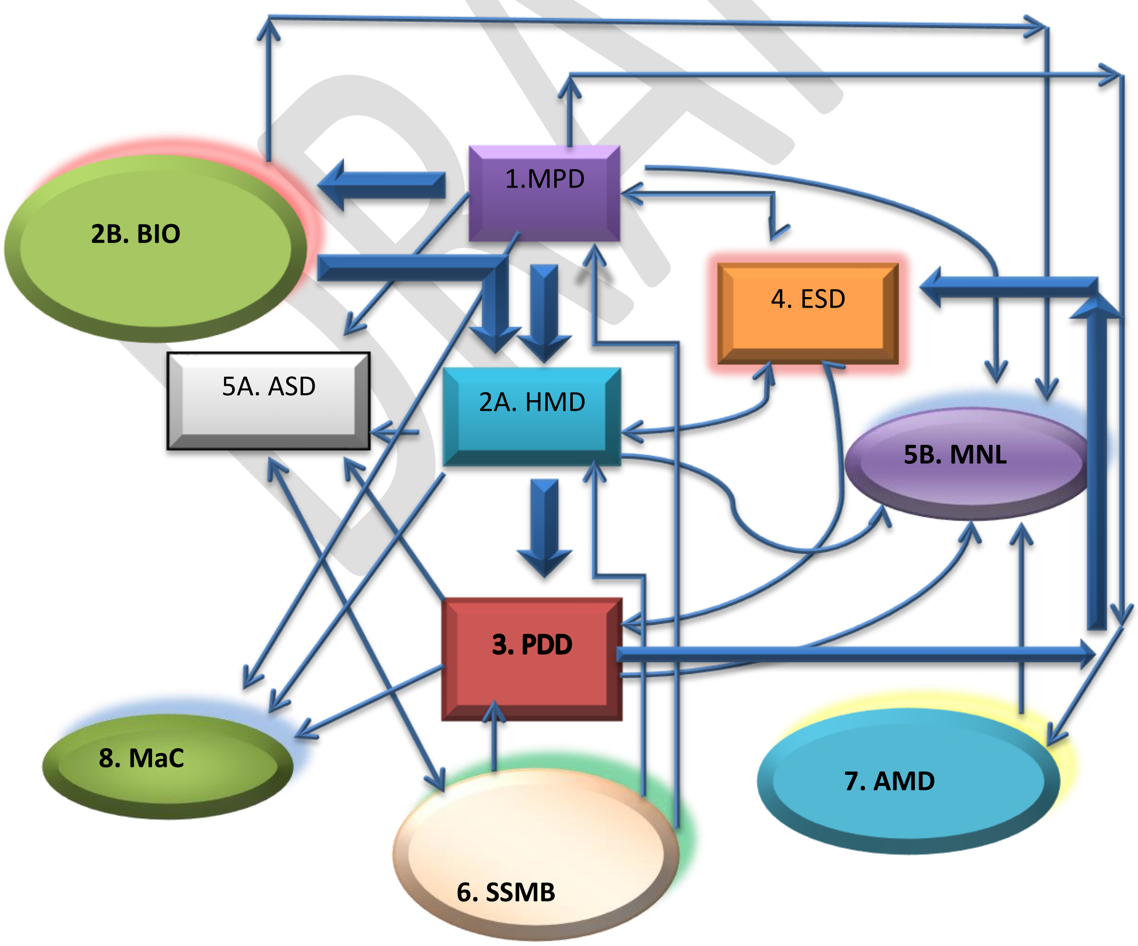
because we try and create jobs, we try and upscale people but we are now servicing entrepreneurs or small businesses (Interview senior manager 12, June 2013).

There is a perception in other units that the SSMB is the main vehicle for achieving the 'public good' mandate of Mintek:

> My understanding is also that the Small Scale Mining division in Mintek is really aimed at training people, enabling them to make a living, enabling communities to have a better life for instance (Interview senior manager 7, June 2013).

Significantly, even units such as SSM, which is primarily dedicated to public good activities, contract with external commercial partners for a fee.

Figure 5.2: Interaction lines between internal strategic units



Formal internal interface mechanisms

These internal relationships are formalized legally, facilitated and monitored via a critical internal interface mechanism. An internal centralized project collaboration register called Systems, Applications and Products (SAP) facilitates internal contracts and service level agreements between the Mintek strategic business units. All work to be done and costs are recorded, thus serving as an internal institutional mechanism for formalizing contract agreements between units. This system runs from the Business Development Unit (BDU). One senior researcher termed these as 'contract-based transactions' because each unit charges a fee for services tendered to other units. External project work is also filed within the SAP system. Such a system regulates internal relationships and facilitates cooperation:

> Okay, within the organisation it's quite simple, we have a project system running on SAP and we basically just sub-contract to one another, it's a very quick and simple, easy process. If you have a scope of work to be done they give you a quote and then when the work gets done then they work according to that quote (Interview senior manager 6, June 2013).

The matrix internal structure based on cooperation and formal contractual relationships provides the foundation for interaction with external partners. Each unit can serve as an external interface mechanism to direct the requests of partners to the full spectrum of expertise within Mintek. All units treat each other as clients for services rendered to each other, and then as partners in collaborative projects. Financial, legal and administrative organizational arrangements exist to facilitate the work of clusters.

It seems likely therefore, that the needs of these clusters with specific strategic goals, as defined regularly in the performance agreement between DMR and Mintek, will impact on and shape the patterns of interaction.

A dedicated external interface structure

The Business Development Unit functions as an external interface structure to coordinate interaction, providing business development support to the R&D and Technology segment divisions. This is achieved by identifying new funding and business opportunities, as well as overseeing new projects that have the potential to move Mintek in a particular direction (interview Senior Manager 1, June 2013). Significantly, the General Manager of the BDU is responsible for the coordination of Mintek's marketing efforts and advice on commercial viability of new technologies.

Active external interface mechanisms for marketing the organization to external clients or partners include exhibitions, advertisements of products, coordination of technical papers by Business Unit managers, conference presentations by individual scientists and engineers, plant visits to existing operating plants by individual scientists and engineers, sales of services and products as well as the website.

The BDU hosts a Technology Transfer Office to provide all units with support and advice on the most effective means for commercializing their intellectual property, to identify and develop new opportunities for technology development and implementation, to identify and protect IP rights, and to regulate contracts for commercial agreements. It serves as an external interface mechanism to facilitate external contractual obligations with clients and customers. The BDU provides these services at a cost – that is, these are contract-based transactions formalized through the SAP system.

The BDU stream hosts another operational sub-unit, the Mining Economics and Strategic Unit (MESU). MESU does mineral economic research, for example, writing mineral development strategies for external stakeholders such as provincial governments, and inter and intra-governmental 'discussions' on mineral development strategies. Internal services are also provided, for example, mineral projection 'briefings' to senior management. Funded research work is also undertaken for international gas, oil and energy cooperation. Services are provided to local government departments in the form of "project management" for the public good.

Analysis of the interview data and organisational documents thus suggests an organisation that is well structured and coordinated, with incentives to promote and support interaction with external ''stakeholders''. A high degree of internal interaction across business units is reported, supporting the claim that Mintek offers a ''one-stop shop''. The degree of internal alignment and collaboration structured by the need for expertise along the minerals value chain is a distinctive feature. The next section analyses how interaction is evidenced in the practices of the engineers, scientists and technologists working at Mintek.

Patterns of interaction with external stakeholders in the practice of Mintek scientists

Drivers of interaction

Analysis of the executive and management interviews provided insight into the pattern of interaction with external stakeholders that we might expect to find amongst the Mintek scientists. Table 5.3 was compiled from an analysis of the interviews. It provides a list of typical internal and external partners and the related forms of interaction, reported by those in each strategic business unit. There are some common trends that can be identified.

Table 5.3: Internal and external interaction of Mintek's strategic business units

Unit	Focus	Internal partners	Typical interaction	External partners and typical interaction
MESU	**SUPPORT** to all units in terms of IP rights issues and **RESEARCH** to internal and external partners on minerals economics	SSMD, MPD, BIO, HMD and the Executive Authority	Contract-based transactions through Line management Briefings with the Minister of DMR through the CEO	**Local government departments** (Project management: Direct consultations)
AMD	**RESEARCH** that leads to the development of metal-based materials through the value addition of metals and minerals	Mainly with MPD and less with other units	Joint ventures - Services in the form of contract-based transaction through Line managers	**DST** (Collaboration in the form of technical support: Direct consultations)
		Post-doctoral students	Internship organised through adverts	**Mines and Metallurgical industry** (Consultative services: Direct consultations)
		Undergrad students	In-service training through adverts or direct recruitment drives	**Mines and Metallurgical industry** (Marketing and selling of Gold catalyst: Direct consultations)
		Business Development Unit	Advice on IP issues terms of agreement - Services in the form of contract-based transaction through general manager	**National Institute of Health USA** (Collaborations: networks)
		Finance	Advise on costing issues. Services in the form of contract-based transaction through line manager	**Pharmaceutical companies** (License agreements for selling of product: Direct consultations)
				Research organizations (Service

				provision: consultations)
				3 HEIs & 2 Science councils (CSIR & MRC) (Collaborations on water and health: networks)
				Local and international marketers (Provision of assay kits: BDU)
				Eskom and Transnet (Consultation work and Service level agreements followed by MoUs)
BIO	Extraction using microorganisms	Esp. MPD, HMD	Services in the form of contract-based transaction through line manager and unit coordinators	**Universities** (Collaboration: consultations) **Consultants (**Collaborations through consultations) **DST and International research brokers (**Networks)
MaC	Process control and instrumentation	MPD, HMD, PDD	Services in the form of contract-based transaction through line manager and unit coordinators	**Universities** (Collaborations: direct consultations) **DST** (Collaborations: direct consultations) **Mineral processing companies** (Consulting and product sale: consultations).
MNL	Mineral characterization	BIO, AMD, MPD, SSMB, PDD	Services in the form of contract-based transaction through line manager and unit coordinators	**Universities** (Collaborations) **DMR** (Contract research through consultations) **NRF** (Contract research through calls for research proposals) **Other science councils** (Collaborations by direct consultations) **Instrumentation companies (**service provision for MNL instruments which is through direct consultations with the service providers)
SSMD	Development and training of subsistence miners for the beneficiation of mineral resources	ASD, AMD, MNL, MPD, PDD	Services in the form of contract-based transaction through direct consultation with the line manager concerned.	**Small-scale miners and subsistence miners** (Technical assistance and business support through direct engagement with communities) **Government departments** (Project management) **DST** (Runding through proposals) **SEDA** (Funding through proposals)
ASD	Analytical services for measuring the	All internal operational	Services in the form of contract-based transaction	**Large geological exploration corporations**

	stoichiometric values of extracted minerals	divisions except MaC & MESU	through line manager concerned and unit coordinators	**Tanzanian government** **Universities** (Collaborations for knowledge sharing and student in-service training) **Consultants** (service provision through existing networks)
ESD	Engineering support	All operating units especially, MPD	Services in the form of contract-based transaction through line manager and unit coordinators	
HMD	Minerals extraction using solvents	MPD, PDD, ASD	Services in the form of contract-based transaction through line manager	**Engineering contractor, Tenova** (Collaborations) **UCT and Veola** (Technical support) **Minataur gold refineries** (Collaborations) **Botswana, DRC, Zambia governments** (Service provision through direct consultations)
MPD	Communution of mineral and process optimization of existing plants	HMD, ASD, AMD, SSMB, MNL	Services in the form of contract-based transaction through line manager	**DMR and DST** (Services through consultations). **CSIR** (Collaborations through DMR) **Geosciences** (collaborations through direct consultations and DMR initiatives) **Universities** (Wits, Natal, Stellenbosch and UCT) (Student recruitment through adverts)
PDD	Smelting of mineral ores and development of high DC furnaces	HMD, ASD	Services in the form of contract-based transaction through line manager.	

First, there are strong financial imperatives driving interaction, to fund 60-70% of the organisation's work. This means that most 'stakeholders' are likely to be industry related, particularly large firms and MNCs given the nature of the minerals sector. On a smaller scale, we are likely to find small firms as partners, given the emphasis on promoting beneficiation and livelihoods in rural and marginalized communities, for the public good. Strategic business units are also clients for each other, which may drive the degree to which they need to identify external stakeholders as clients. For example, the Analytical Services division, which is quite strongly connected internally to offer services to other Mintek units, explained how they are led to seek external partners, such as Anglo and Lonmin with whom they have worked in the past:

> …our first point of call would be either if we go out and speak to the industry and say 'we don't have a lot of work at this point, we have a lot of capacity, do you need this kind of work done for yourselves?' And then if they are agreeable to that we then take the work (Interview senior manager 5).

Second, it is clear that business units will differ significantly in the scale and nature of interaction. Some strategic units are more likely to interact with external stakeholders given the nature of their specific expertise and focus. The type of stakeholders and the nature of interaction are also likely to differ, depending on the stage of the value chain the strategic business unit engages with – upstream, horizontal or downstream processes. For example, downstream linkages are observed in the AMD unit's research on ways of beneficiating mineral products, which leads to interaction with health institutions, pharmaceutical companies, mining and metallurgical industries. SSMB unit in turn, undertakes project management work on behalf of government departments and community upliftment for poverty eradication:

> …because of the area that we are looking at, … because our one is more community based and stuff like that we don't actually have a lot of interactions with universities at the moment (Interview senior manager 12, June 2013).

Project management and consultation have been the most frequent forms of interaction with clients. With subsistence miners, ASD is involved in collaborative work with the SSMB unit, on condition that the potential for commercialisation of a subsistence miner is identified. Miners will be assisted with setting up appropriate structures and facilities, as well as training. For those units that work in the upstream stage of the value chain, dealing with issues of mineral exploration to study the economic viability of mining a specific ore, the typical interaction would be

> … from the people that actually use the results which would be the geologists or the geo chemist that work with the geologist in the mines or even the quality managers who would want to have another lab look at the results. Perhaps they have a specific lab that they use for analysis and then they usually will say 'are these results right?' and then they'll come to us and say 'would you look at this for us?' (Interview senior manager 5, June 2013).

Third, external stakeholders will not only be firms, but could be other knowledge producers, both national and international. Universities or other science councils particularly interact in relation to horizontal stages of the value chain. Collaboration with universities needs to be understood in the context of one of the greatest challenges articulated by senior management: "sourcing and retaining world class expertise'' (2013/14 Shareholder compact: 3). The main incentive to work with universities articulated by business units like ASD, BIO and MNL is ''cheap labor'', in the form of students, rather than employing scientists to work on projects:

> We do collaborations with universities. We've got students that we are sponsoring or paying for their bursaries and then over like December holidays they come in to work for us, and then when they complete their studies then we absorb them to work for Mintek (Interview senior manager 10, June 2013).

Another motivation driving interaction is where universities and other science councils (such as CGS and CSIR) have advanced equipment and more knowledgeable staff with expertise that is not found in Mintek:

> …when we have technical problems with our methods and things like that we are now in a position to go and say '*this* method doesn't seem to be giving us the correct results, can you help us look into *why* this is the case and help us to fix it?' (Interview senior manager 5, June 2012).

Fourth, government is a key external partner, including other African governments, DST and DMR, and parastatals such as Eskom and Transnet.

The next sections describe and analyse the data from the survey of scientists, to reveal the patterns that result from such drivers of interaction, and corroborate the pattern suggested from the interviews.

The scale of interaction

At Mintek, a total of 214 scientists were identified, out of a total staff complement of 679 (reported as at December 2012). A realized sample of 83% was obtained, a total of 179 scientists, engineers and technologists. The analysis is based on this sample dataset.

A quarter of scientists and engineers do not interact with external stakeholders

Just over a quarter, 27% of the sample of engineers, scientists, technicians and heads of units, indicated that they do not interact with external stakeholders at all. This was the largest group at the four science councils. There were few marked differences in age, gender or qualifications between those who reported they do and do not engage. Those who do *not* interact were somewhat more likely to be African (50% of those who engage were African, against 66% of those who do not engage), and at lower ranks. Of note, 42% of those who do not interact were engineers, while 31% were scientists; and 44% were in the R&D division, and 56% in the Technology segment units.

The main reasons provided by this group who do not interact relate to the claim that interaction is not central to the scientific roles in that field or discipline. Thus, two thirds of those who do not interact reported that a very important reason is that it is not appropriate given the nature of their scientific field or discipline. A second important reason is that it is not central to their role, and a third is perceived to be stakeholders' lack of knowledge of the work of the science council. This may be explained in relation to the cluster organizational system at Mintek, whereby some strategic business units will act as consultants within a cluster, interacting internally with scientists from other business units.

Can we infer that interaction is seen as an integral part of the roles of more than three quarters of Mintek staff? Examination of the barriers experienced by those who *do* interact shows a very different set of limitations reported (although the list included similar reasons). Here, the most common barriers relate to the resources and support for interaction: funding, time, human resources and institutional systems (Table 5.4). The difference between the two groups suggests that interaction is widely accepted as part of the role of Mintek scientists and engineers, but that a group of staff tends to interact internally, providing services to clusters and teams who may be directly engaged with firms or government partners.

The analysis going forward focuses on discerning patterns amongst the group of 131 researchers who interact with external partners.

Table 5.4 : Barriers to interaction: Mintek

Limited financial resources for competing institutional priorities	3.41
Sustainable external funding	3.41
Competing priorities on time	3.37
Negotiating access and establishing a dialogue with external partners	3.27
Too few research staff	3.23
Lack of clear institutional policy and structures to promote scientific engagement or social responsiveness	3.07
Institutional administration and bureaucracy does not support scientific engagement with external partners	3.03

A strong degree of homogeneity in the pattern of external partners

The WAI analysis suggests a common set of knowledge and firm partners with whom the scientists and engineers at Mintek interact most frequently (Table 5.5). South African universities and science councils, followed by firms of various sizes, are the most common types of partner. Notably, the WAI is very similar for the four most frequent partners, ranging from 3.0 to 2.7. Similar numbers of scientists report that they interact on a moderate to wide scale (3 and 4) with these knowledge and large firm partners.

Table 5.5: Most common partners of Mintek scientists: WAI

		Mintek					WTotal	WAI
		<>	1	2	3	4		
P24	South African universities	131	13	29	*40*	*49*	387	*3.0*
P26	South African science councils	131	16	31	*44*	*40*	370	*2.8*
P20	Multi-national companies	131	22	30	*32*	*47*	366	*2.8*
P18	Large South African firms	131	27	21	*43*	*40*	358	*2.7*
P19	Small, medium and micro enterprises	131	27	32	47	25	332	2.5

The data reflects the number of interactions, rather than the number of partners. Table 5.6 thus groups those who interact on a moderate to wide scale (3 or 4 on the Likert scale) in terms of the total number of partners they reported. The number of partners reported by each individual researcher can provide a measure of the degree to which scientists are networked. For instance, at one research university surveyed, the majority of academics reported only a single partner, suggesting traditional academic dyadic relationships rather than insertion into networks (Kruss et al 2013). In contrast at Mintek, seven scientists reported interacting on a moderate to wide scale with only a single partner (Table 5.6). Two individuals reported as many as 18 different partners. The majority of the scientists indicated between 4 and 10 partners, with the average, mode and median number of partners being 7.

Table 5.6: Number of active partners of distinct types: Mintek

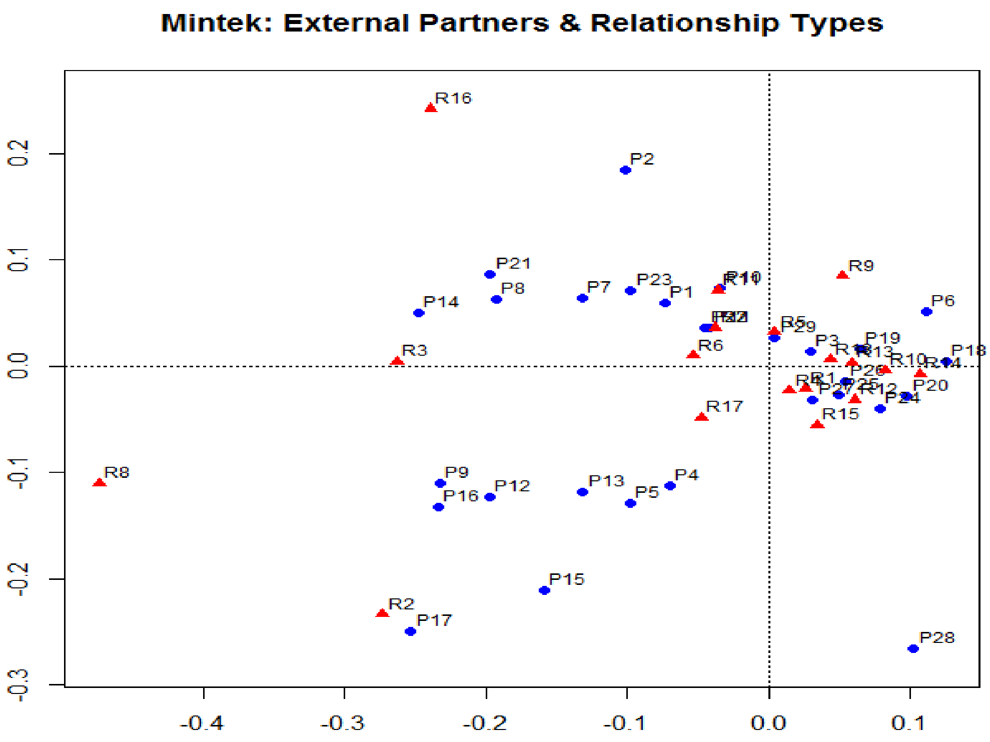
Number of partners (rating of 3 and 4)	Number of scientists	Percentage	Cumulative percentage
0	1	0.76	0.76
1	7	5.34	6.11
2	9	6.87	12.98
3	13	9.92	22.9
4	16	12.21	35.11
5	7	5.34	40.46
6	11	8.4	48.85
7	17	12.98	61.83
8	10	7.63	69.47
9	7	5.34	74.81
10	7	5.34	80.15
11	8	6.11	86.26
12	4	3.05	89.31
13	4	3.05	92.37
14	3	2.29	94.66
15	3	2.29	96.95
16	1	0.76	97.71
17	1	0.76	98.47
18	2	1.53	100
Total	131	100	

This suggests that the majority of scientists at Mintek have a large number of partners, and a high degree of networking. Of course, a scientist may be involved with seven partners on seven projects or seven partners on one networked project. Inspection of the examples provided by scientists of their best case of interaction (and those reported in Table 5.3 above) confirms that on a specific project, there are networks of multiple partners. Some examples of best cases of interaction provided by the scientists include a network between mining houses, engineering design companies and consultants that focuses on beneficiation methods for ores flow sheets, or a partnership between Magnesium SA, the IDC and an international company, or a network between an international mining company, Mintek, a local university and a number of consultants from South Africa and Europe, focused on the development and optimisation of a bio-leaching process to treat concentrates. Other examples include where a government department involves Mintek scientists in research and development work for the manufacture of new products, through the Advanced Metals Initiative, or where the Department of Minerals and Resources involves Mintek in a partnership with affected communities to clean contaminated old mine sites. It seems that the Mintek scientists tend to interact actively with a distinct, fairly homogenous set of partners, and it is likely that many interact with multiple partners in networks. The next section investigates whether this is indeed the pattern of partners, and the kinds of relationship typically entered into with these distinct groups of 'stakeholders'.

Three clusters of external partners

Figure 5.3 reflects the results of a correspondence analysis of the associations between external partners and types of relationship. The dimensions explain 63.6% of the variability, with dimension 1 more significant for the interpretation of associations (dimension 1, 44.2% and dimension 2, 19.4%).

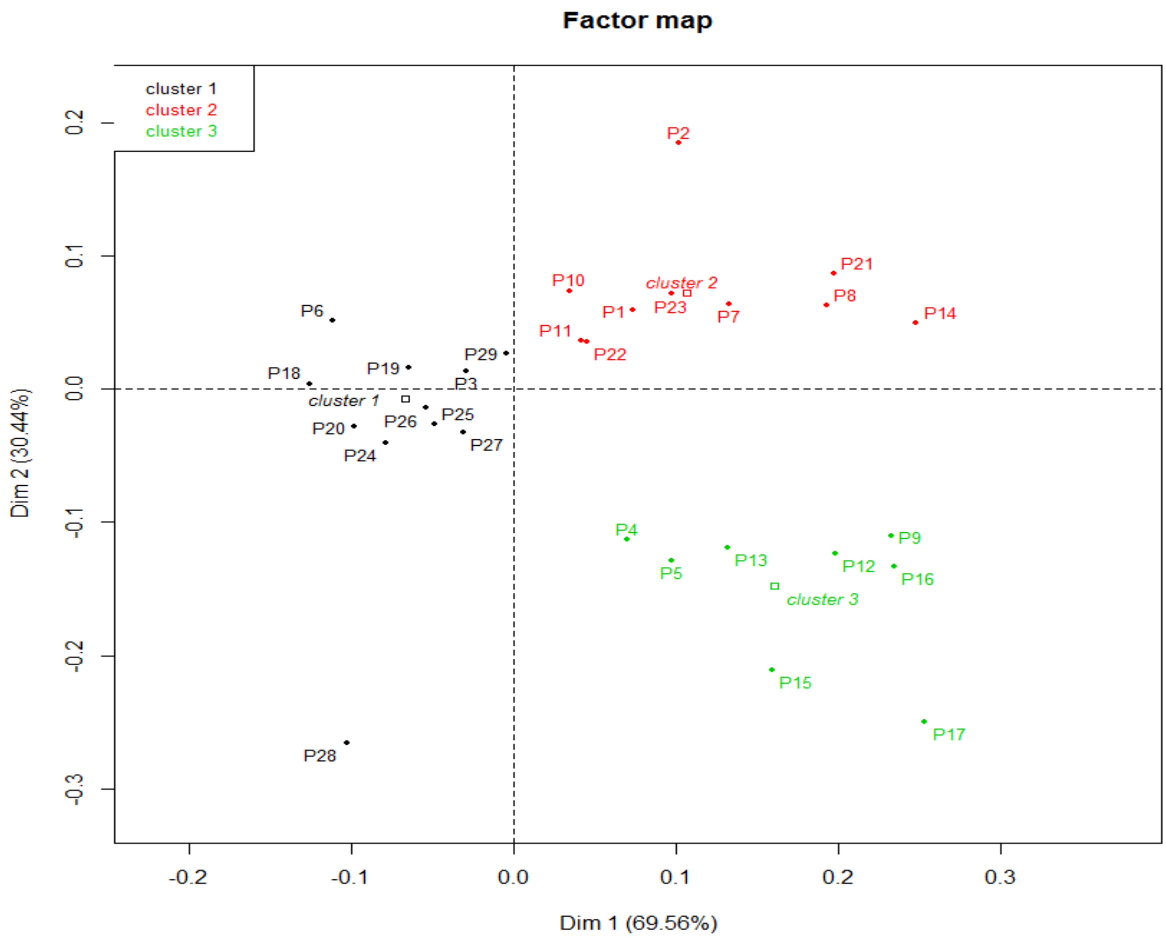
Figure 5.3: Correspondence analysis of associations between Mintek partners and relationship types



It reflects that indeed, there is a strong degree of homogeneity in the interactive activity of Mintek scientists. A large set of points (where P represents partners, R represents types of relationship) are strongly associated with each other, and concentrated to the right of the point of origin, along dimension 1. These represent the core profile of partners and relationships most frequently and typically found at Mintek. However, there are also a number of potentially significant associations that are more spread around the axes, and a few that are widely dispersed. These may reveal distinctive variations and niche activity in the practice of Mintek scientists.

Figure 5.3 is very cluttered and the most important associations we would want to investigate are compressed around the point of origin. Hence, we conducted cluster analysis (Figure 5.4) in order to reduce complexity, and to show the associations more clearly. The partners grouped in the same cluster are those with the most similar profile in terms of the types of relationship with them. Figure 5.4 depicts the three clear clusters of partners that emerge from the analysis.

Figure 5.4: Cluster analysis of partners



The strongest trend observed, the most typical partners, reflects interaction that promotes Mintek's mission of *global competitiveness,* but at the same time, its *scientific reputation*. Thus, Mintek scientists are most likely to interact in similar ways with a cluster of national government departments, national regulatory agencies, large SA firms, small, medium and micro enterprises, universities, science councils, and funding agencies (Cluster 1: P3, 6, 18, 19, 20, 24-27, 29 in Figure 5.4). We have seen that the knowledge and firm partners are the most frequent, on a similar scale. These partners relate to the core mandate of Mintek, and its technical programmes oriented at national economic development.

Cluster 3 includes a different, and distinctive set of partner, related to community and economic development: local and provincial government agencies, individuals and households, specific local communities, NGO's, development agencies, community organisations, small scale and commercial farmers and sectoral organisations (Cluster 3: P1, 2, 7, 8, 10, 11, 14, 21, 22, 23 in the bottom right hand quadrant of Figure 5.4). These partners are more related to Mintek's technical programmes in relation to regional economic development, it seems. This cluster is further away from the point of origin, which indicates that it is not as strong a trend as the first cluster. So for example, inspection of the WAI shows that 89 scientists reported interaction with a university on a moderate to wide scale, but only 41 with local government agencies, or 26 with a specific local community. The third

		Total number of responses	Not at all	Isolated instances	On a moderate scale	On a wide scale	(Frequency multiply by Weight	Weighted average index=F*W/ Frequency

cluster thus represents a niche area or emergent trend, most likely the focus of units where research is related to the end stages of the value chain, such as the closure of mines, or to beneficiation in relation to livelihoods at a local community level.

Scientists engage with another set of partners that are related to the social programmes, focused on skills development and educational initiatives: clinics and health centres, schools, welfare agencies, trade unions, civic associations, social movements, political and religious organisations (Cluster 2: P4, 5, 9, 12, 13, 15, 16, 17 in the top right hand quadrant in Figure 5.4). These are located away from the point of origin along Dimension 1 in Figure 5.3. Inspection of the WAI shows that these are a frequent partner for a very small number of scientists, and the majority do not engage with these partners at all. For example, only 25 scientists interact with schools (P5) on a moderate to wide scale, 10 scientists interact with partners in clinics and health centres (P4) and 2 with civic associations. It may be that interaction with these partners is not directly related to Mintek's core research business, but to a corporate social development mandate.

These questions lead us to consider the type of relationship with which scientists engage partners in these three distinct clusters.

The most frequent patterns of types of relationship

The most frequent types of relationship of Mintek scientists are summarized in Table 5.7

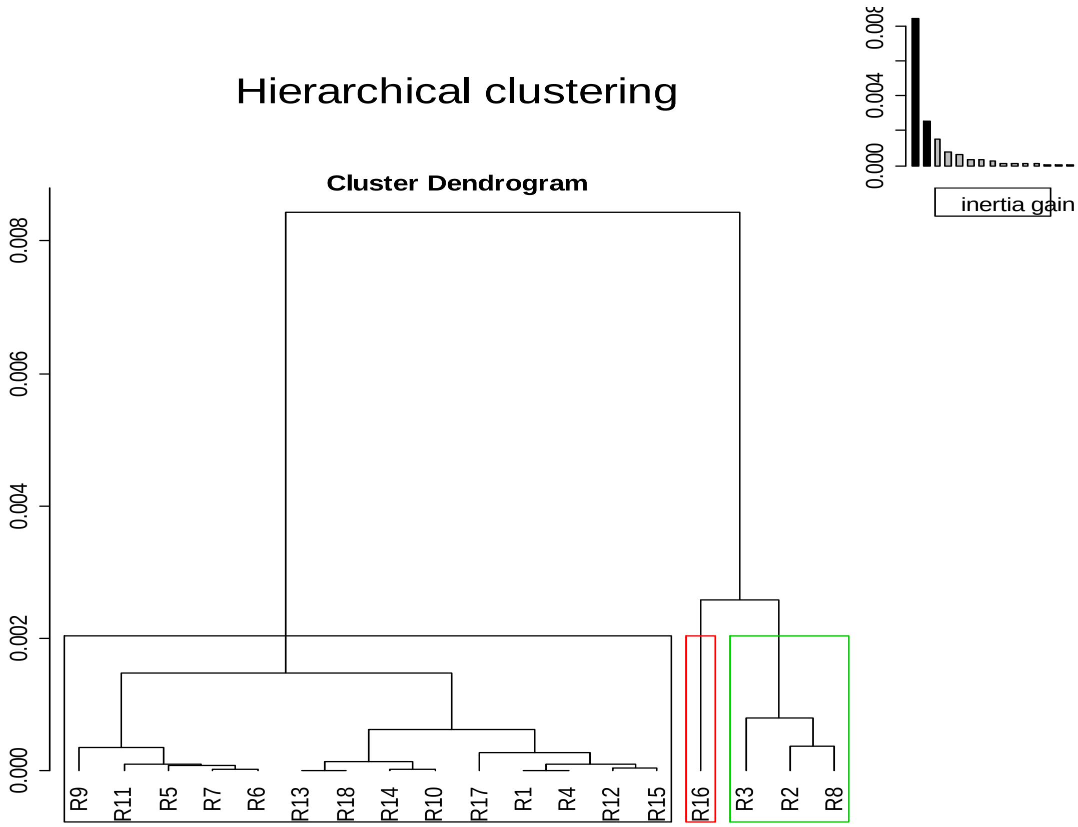
Table 5.7: Most common types of relationships

			1	2	3	4	F*W	WAI
10	Design, prototyping and testing of new technologies	131	12	20	35	64	413	3.2
15	Collaborative R & D projects	131	10	21	43	57	409	3.1
14	Contract research	131	11	28	39	53	396	3.0
13	Technology transfer	131	12	34	35	50	385	2.9
4	Continuing education or professional development	131	18	27	36	50	380	2.9
12	Research consultancy	131	16	32	37	46	375	2.9
1	Education of post-graduate students so that they are socially responsive	130	24	20	46	40	362	2.8
11	Monitoring, evaluation and needs assessment	131	30	34	33	34	333	2.5

Again, it is evident that there is strong homogeneity between the first seven types of relationship, most strongly related to technology and innovation activities, where the WAI ranges from 3.1 to 2.8. Most of these types of relationship require direct interaction between partners, as well as the exchange of formal and tacit knowledge. So, Collaborative R&D projects are more frequent than consultancies, for example. There is also a capacity building dimension in the frequency of continuing and post-graduate education. The 'monitoring, evaluation and needs assessment' type of relationship is likely to take very specific forms at Mintek, related to the early, more exploratory stages of the value chain, to assess viability of deposits, or at the late stages, to provide advice to inform beneficiation or markets.

Figure 5.5 reflects the three clusters of types of relationship that emerge from the cluster analysis, here using the format of a dendogram rather than a two dimensional table. This is useful to show how the clusters are constructed at higher levels of aggregation. Aggregation into fewer clusters allows us to identify strongest trends. However, disaggregation as in the dendogram below, allow us to identify nuance, in the form of niche areas of activity of small groups of scientists, or emergent trends, or total outliers of activity.

Figure 5.5: Hierarchical cluster analysis types of relationships



The predominant types of relationship

The strongest trend at Mintek, and the most frequent types of relationship, is depicted in the first cluster in Figure 5.5, which shows a large grouping of types relationships that have similar profiles, and that can be grouped into sub-clusters at lower levels of disaggregation. Cluster 1 here mirrors Cluster 1 of partners in Figure 5.4 above, in that it reflects the core mandate of contributing to national economic development. Likewise, cluster 2 here mirrors cluster 3 of partners, addressing regional and local economic development, while cluster 3 here mirrors cluster 2 of partners, in relation to social programmes.

Cluster 1 of types of relationship includes two main sub-clusters. The larger sub-cluster, on the right hand side, includes the most frequent types of relationship, more likely engaging with economic development partners such as large mining firms, and oriented to the core mandate of Mintek. That is, design and prototyping, collaborative R&D, contract research, technology transfer, consultancy, education of post-graduates, commercialization and participatory research networks.

The smaller sub-cluster on the left hand side includes Design and testing, monitoring and evaluation, policy research, expert testimony, and customized training (R9, 11, 6, 5 and 7). These types of relationship are more likely with SMMEs, and government partners.

We can further examine the association of types of relationship with distinct partners, through an analysis of Figure 5.3 above, to highlight nuance. If we consider interaction with *firms* (P18, P 19, P 20) and other economic agents such as farmers (P21, P22) we find a close association with the types of relationship in the larger sub-cluster. For example, Mintek scientists who interact with large SA firms also interact with Multi-national companies, and tend to do so through contract research (P20/P18 and R14). Bear in mind that South African mining houses such as Anglo American have become MNCs with a strong local base. The types of relationship with Small/Medium and Micro enterprises are distinctive, in that they are more likely to be involved in design, prototyping and testing of new technologies, and technology transfer (P19 and R10/R13), which reflects the strategic objectives of the Mintek regional economic development programmes. This reflects their mission of supporting the growth of the junior and small mining sector. Those who interact with local government agencies, commercial farmers and sectoral organisations tend to do so in terms of offering policy research, advice and analysis, or expert testimony (P1, P22, P23, and R6/R7 in the top left quadrant near the point of origin). It is possible that these relationships point to assessment of the viability of mineral deposits, or treatment of environmental damage. There also seems to be a small niche of interaction with NGOs through monitoring, evaluation and needs assessment types of relationship (P10 andR11 in the top left hand quadrant, located close to the second dimension and not very far from the first dimension).

Mintek scientists are also more likely to interact with SA universities through research consultancy and contract research types of relationship (P24 and R12/R14 in the bottom right quadrant). This suggests that they bring in university scientists for specific complementary expertise, in a formal and structured manner. When interacting with international universities, they are more likely to engage through design, prototyping and testing of new technologies, and technology transfer, but also through research consultancy (P25 and R10/R12/R13). This suggests that international universities are more involved in applied knowledge work with a potential financial return, perhaps in a more collaborative manner, to contribute missing expertise. The types of relationship most common to interaction with international science councils is education of post-graduate students, continuing education or professional development, and collaborative R&D (P27 an R1/R4/R15). This suggests that global knowledge flows are critical for capacity development of current and future scientists. Likewise, there is a niche of interaction with development agencies through customised training and short courses, policy research, advice and analysis, expert testimony, and monitoring, evaluation and needs assessment (P11 and R5,R6, R7, R11 in the same quadrant and relatively close to P10). An example was provided by a chief technician who reported setting up pottery workshops as part of the Mintek downstream beneficiation strategy, in partnership with a development agency.

A small but significant pattern of economic development oriented types of relationship

Of note, the second cluster of types of relationship (Figure 5.5) consisted of one variable only – community based research projects. This cluster represents a significant trend, in line with the specific Mintek commitment to contribute to regional developmental priorities, through activities in the downstream value chain. These are aimed at poverty alleviation and employment creation by promoting the mineral-based economies of rural and marginalized communities. It is likely that these interactions are related to projects led by the Small Scale Mining and Beneficiation unit, which offers development and training to small-scale and subsistence miners (see Table 5.3 which identifies the most typical interactions reported in interviews for this unit). Examples of such community oriented research projects were provided by scientists, revealing that they primarily involved training and technology transfer in relation to livelihoods and job creation (Box 5.2). Analysis of specific points of partners and types of relationship associated with one another in Figure 5.3 can provide further insight. For example, small scale farmers are associated with a specific local community and community organisations, and the closest type of relationship is community based research projects and collaborative curriculum design (suggesting some form of training programmes offered) (P21, P8 and P14 with R3 and R16 in the top left hand quadrant of Figure 5.3, at some distance from the point of origin).

Box 5.2: Examples of types of relationship around community economic development

- The conduct of community research to identify needs and provide training and skills development, especially to people in mining industries, partnered with communities, mining houses, government departments and municipalities.
- A project to teach community miners to use safer products by providing them with free technology.
- Work with the MQA and DMR to train and legalise small scale miners
- Work with a local community and the Small Business Development Agency to train people with little or no education on hard rock mining, with certification of competence by MQA
- A job creation project using fertiliser production technology but using readily available material and considering environmental impact, in partnership with a government department, a university, a local municipality and a local mine
- A project to develop a standard grading system for gemstones in the Northern Cape that led to the establishment of a workshop and training for local miners. This is part of a larger project reported to formalise the semi-precious minerals sector in the Northern Cape where they are currently mined illegally, losing revenue and employment. The project stakeholders included MINTEK, DMR, local mines and local municipalities. The DMR is in the process of assisting miners with obtaining prospecting rights. Mintek is conducting research on the equipment required, mining, beneficiation and markets. The expected outcome is a beneficiation hub where semi-precious stones are beneficiated into sellable puducts as jewellery

A small set of social development oriented types of relationship

The third cluster (Figure 5.5) consists of voluntary outreach programmes, collaborative curriculum design, and clinical services (R2, R3 and R8). These appear to be atypical service forms of interaction for Mintek, unrelated to the core research mandate, but related to the social programmes. Further inspection revealed that there were very few Mintek scientists included in this cluster, so that these represent very small niches of activity. These types of relationship are associated with Cluster 2 of partners (Figure 5.4).

Further inspection of the association between points of partners and types of relationship on Figure 5.3 reflects an association between religious organisations, social movements and voluntary outreach programmes and clinical services and patient or client care (P15, P17 and R2, R8 in the bottom left hand quadrant of Figure 5.3). This suggests the kinds of service interaction that scientists might engage in as citizens outside of the work space, which are not integral to their role of knowledge production. Involvement in these does not necessarily require scientific expertise, and they also represent a form of community service, or corporate social responsibility.

There is however, evidence of interaction oriented to Mintek's social programmes, to contribute to skills development and education. As one engineer reported:

> I have been assisting with the Mintek run Minquiz national mathematics and science competition for high school learners. My responsibilities included overseeing provincial competitions with the aid of the provincial organiser, and delivering a presentation to the learners that gave an introduction to Mintek and some of our exciting research areas.

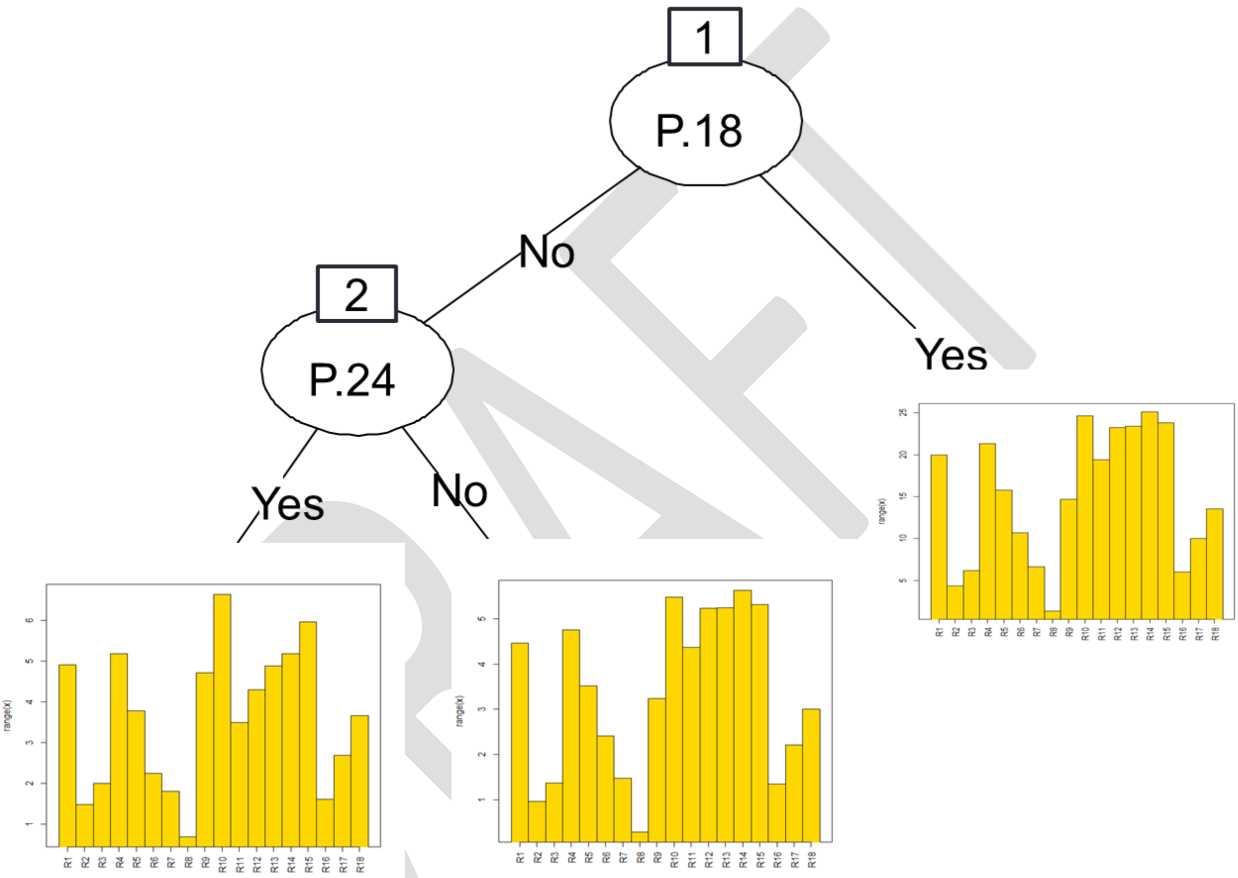
There is more active involvement reported with schools, because of this kind of organisational commitment to skills development.

Interaction with large firms and universities

To deepen our analysis of the scale and nature of different forms of interaction with specific types of partner, we used the technique of Classification trees. The first step is to conduct a cluster analysis on type of relationship variables, and then, assign each scientist to the cluster for which they had the highest mean value (so, they may be involved in other types of relationship, but this reflects their interaction **on a widest scale**). For Mintek, five clusters were yielded, with the largest numbers of individuals, 62, in cluster 5 (interacting through M&E, consultancy, technology transfer and contracts) and 45 scientists in cluster 4 (design and testing of new interventions and of new technologies).

We then used type of *partner* as the splitting variable, resulting in the tree in Figure 5.6 The selected complexity parameter is 0.01 and the resulting most stable tree, with the lowest average misclassification, has three branches. There are two main splits – interaction with large firms, and interaction with South African universities.

Figure 5.6: Mintek classification tree by external partners



We can then examine the types of relationship most likely to characterize interaction with large firms (block 5, the node of ‘yes’ to interaction with large firms, standardized so that it is weighted to the full sample to reveal trends more effectively). The analysis reveals that in their interaction with large SA firms, Mintek scientists most commonly engaged in monitoring, evaluation and needs assessment types of relationship, followed by consultancy, then technology transfer and contracts. These would be categorised as service forms of interaction, in terms of our framework, those which are more strongly driven by the financial imperatives of public research institutes and the reactive strategies of firms, but they could also take network forms including multiple partners, and driven by the proactive strategies of firms. Typical examples include testing a new sorting technology from Russia on different samples and mines in South Africa for a large mining firm; developing new catalysts for glycerol oxidation reaction, in partnership with a large multi-national mining company; working with a platinum mine to create an online measurement device.

The Mintek interpretation of "M&E and needs assessment'' is very specific, related to their applied research core activities and services to the mining sector in the mineral exploration and process extraction phases of the value chain. Examples of best practice provided shed light on these types of relationship, indicating strong environmental concerns (Box 5.3).

Box 5.3. Monitoring and evaluation types of relationship at Mintek

- Monitoring water samples from the mines for X partners (large MNCs and large SA mining houses).
- Providing analytical support for a big mining concern to help them decide if their processes are working effectively.
- Alternative furnace technology assessed for suitability in new fields, one where environmental issues were of concern and a second where potential improved recovery may be possible. Both applications were successfully demonstrated as technically viable, making industrial implementation a possibility.
- A consultancy project to modify the flotation circuit of a mining company, where Mintek was responsible for conducting pilot plan tests.

The nature of research and the types of relationship are different if the main partner that a scientist interacts with is not a firm (No to P18, Yes to P 24), but a university (node 3). Here, the most typical relationships were revealed to be ''clinical services or client care". This strong association can be explained by the fact that there were only 7 individuals who interact through this type of relationship, and 6 of these interact with universities. This relates to a core of downstream beneficiation research and innovation activity using minerals in health applications. Some examples of best practice cited illustrate this trend:

- Drug discovery, screening of compounds submitted by external partners in universities and mutually establishing a way forward.
- Gold based compounds research for medical use in HIV discovery with university X.
- Research on new technologies for HIV treatment as well as new technologies that will facilitate development and/or discoveries of new products in the drug discovery realm. The scope of the research undertaken also allows for post-graduate (Masters and PHD) student

development. This is achieved through the establishment of collaborative networks with local and international universities.

- Developing diagnostic kits for Rift Valley fever virus.
- Commercialisation of Malaria testing kits.

Of note, the next most common type of relationship with universities is design and testing of new interventions, and of new technologies, followed by joint commercialization of a new product. These reflect the national policy imperative to encourage universities and science councils to collaborate and commercialise their IP, through instruments such as the Innovation Fund and THRIP. Examples cited are:

- A project to improve liberation of minerals in using microwave energy, partnering with universities and the CSIR.
- A division that serves and interacts with mining houses, metallurgical companies and small engineering firms to offer solutions to the challenges they face in extraction and pre-concentration techniques, reported that they collaborate with South African universities (those offering Chemical and metallurgical engineering courses).
- A project to implement safe ways to remove carbon monoxide from gold and iron, partnered with universities in Paris.

Collaborative curriculum design is not a common type of relationship, but there is evidence of collaborative networks around teaching, as a member of a unit responsible for sustainable development explained:

> I manage a programme of mines rehabilitation for the national government. I set the examples to educate new government employees within that department to make them more aware of risks and other matters that pertain to their work. This is done in the form of a course that is funded through a different channel and coordinated by X (a university).

The least significant types of relationship for their interaction with universities relate to the applied, income generating research activities of Mintek – research consultancy and M&E and needs assessment – the most common types of interaction with firms.

The interactive activities reported by scientists at this mission-oriented PRI thus reflect that they tend to operate in strong alignment with Mintek's strategic objectives, supported by the external and internal interface structures. The form of interaction includes bi-directional networks that contribute to address specific problems but also contribute to knowledge. They are strongly linked with key large firms in the sector, they collaborate with universities and they provide design and testing service forms of interaction to address the needs of small miners and communities. The impact of this collaborative and network activity should be reflected in outcomes that are of benefit to Mintek, to their partners and to the national system of innovation.

What are the outputs, outcomes and benefits of interaction?

Analysis of the WAI shows that for most scientists, the most frequent **outputs** take a traditional applied science form. Table 5.8 reflects the applied and strategic nature of much of Mintek research. The most common outputs are reports, policy documents and popular publications, with academic publications ranked second together with scientific collaboration. The first technology or innovation related output - new or improved processes - is ranked fifth, but scientific discoveries are ranked below that. Scientists reported only 24 interactions that typically resulted in scientific discoveries (4 on the Likert scale), and more interactions did not typically result in scientific discoveries (70 responses of 1 or 2 on the Likert scale).

Table 5.8: Most common outputs of interaction of Mintek Scientists: WAI

	Outputs	<>	**Not at all**	**Isolated instances**	**On a moderate scale**	**On a wide scale**	**WTotal**	**Weighted average index=F*W/F**
			1	**2**	**3**	**4**	**F*W**	**WAI**
O4	Reports, policy documents, popular publications	131	7	19	50	55	415	3.2
O6	Scientific collaboration	131	20	29	43	39	363	2.8
O2	Academic publications	131	22	28	41	40	361	2.8
O1	Post-graduates with relevant skills and values	131	24	30	38	39	354	2.7
O10	New or improved processes	131	29	28	41	33	340	2.6
O11	Scientific discoveries	131	***32***	***38***	***37***	***24***	315	2.4

An example cited by a scientist who heads up one of the research units illustrates the outputs of a typical academic collaboration with university partners:

> Our best example of engagement with external partners is our long running (6 years) collaboration with Prof…. at the University of….The focus has been the development of HIV drug discovery research. To date the collaboration has yielded 3 MSc Graduates, two journal articles, a number of oral and poster presentations at local and international conferences, a joint collaboration with an international research group, and a number of joint funding proposals.

An example of the outcomes from design of a new process was provided by a female scientist, the head of a unit, who partnered with a large firm:

> The focus was to test the metallurgical performance of novel technologies to recover valuable metals from copper and cobalt refinery tailings. These technologies have the potential to transform increasingly common low grade metal resources into proven reserves. The outcome was a procedure, or technique that benefits the industry partner. A plant is being built for the recovery of Cu and Co.

The WAI ranks the most frequent **outcome or benefit** (Table 5.9) from interaction as scientific and institutional reputation (B17). This provides strong empirical support to our framework, which posits that scientists will value interaction if it is integral to their reputation and to developments in their scientific discipline. What stands out at Mintek is that 131 scientists reported 105 instances of interaction on a moderate to wide scale that enhanced their scientific reputation. Moreover, a relevant research focus and new research projects, (B16), and training and skills development (B6), are both the frequent benefit of 91 interactions of the 131 Mintek scientists, also linked to enhancing reputation.

Table 5.9: WAI of benefits and outcomes

	Benefits	**<>**	**Not at all**	**Isolated instances**	**On a moderate scale**	**On a wide scale**	**WTotal**	**WAI**
B17	Scientific and institutional reputation	131	11	15	54	51	407	3.1
B16	Relevant research focus and new research	131	12	28	42	49	390	3.0

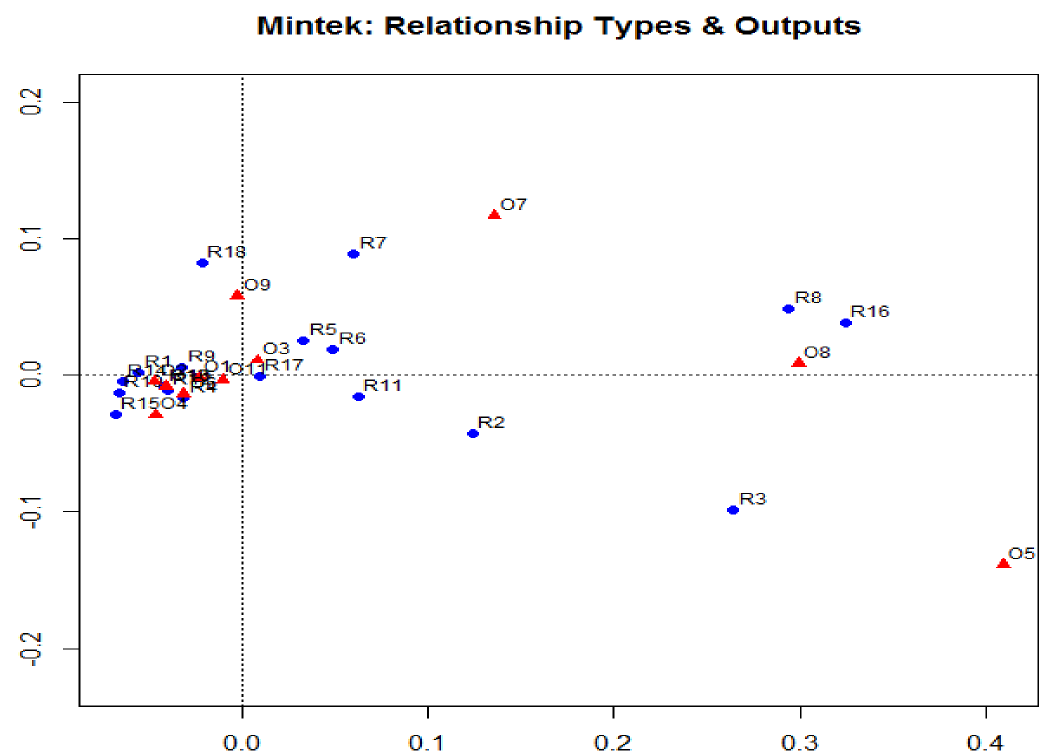
	projects							
B6	Training and skills development	131	18	22	41	50	385	2.9
B18	Theoretical and methodological development in an scientific field	131	18	24	44	45	378	2.9
B10	Novel uses of technology	131	27	30	40	34	343	2.6
B9	Firm productivity and competitiveness	131	28	27	49	27	337	2.6

Relationships types associated with outputs, outcomes and benefits

The examples above suggest that different types of relationships are likely to result in scientific discoveries, or in new and improved processes, or enhanced scientific and institutional reputation.

The **outputs** and the types of relationship that produced them are very strongly clustered around the point of origin, with a strong degree of association as indicated in Figure 5.5.

Figure 5.7: Mintek relationship types and outputs



A number of associations stand out and are worth highlighting:

- Scientific discoveries (O11), Post-graduates with relevant skills and values (O1) and dissertations (O3) are the located closest to the point of origin and therefore are the most common outputs generated by research consultancy (R12), continuing education or professional development (R4), and/or design and testing of new interventions or protocols (R9).

- New and improved products (O9), new and improved processes (O10), academic publications (O2), and reports, policy documents and popular publications (O4), are commonly produced by design, prototyping and testing of new technologies (R10), technology transfer (R13), collaborative R&D projects (R15), contract research (R14), participatory research networks (R17), joint commercialisation of a new product (R18), and/or education of post grad students to that they are socially responsive. This reinforces the significance of collaboration and network types of relationships for Mintek scientists, whether with firms or universities.

- The association between new and improved products (O8) and joint commercialization types of relationship (R18) is a significant focus for Mintek scientists, but not the most common. Scientists reported 56 new or improved products as a frequent output (3 or 4), but 74 outputs of new and improved processes on a moderate to wide scale (3 or 4).

- Spin-off companies (O7) and Community infrastructure and facilities (O8) are outliers likely to result in isolated incidences, and associated with clinical services (R8) and community based research projects (R16). One example cited by a senior technician was an incubator that helps to create jobs for "the disadvantaged people" by teaching them how to farm poultry, funded by the DTI. It is not clear if this is a kind of corporate social responsibility or directly related to core research of this scientist, in the field of industrial minerals.

When we extend our analysis to consider the **outcomes and benefits of interaction**, a more nuanced picture emerges beyond traditional scientific outputs. There is a dense set of points on the first dimension to the left of the point of origin (Figure 5.8) and Figure 5.9 highlights the three clusters of outcomes associated with similar profiles of types of relationship.

Figure 5.8: Mintek relationship types and outcomes and benefits

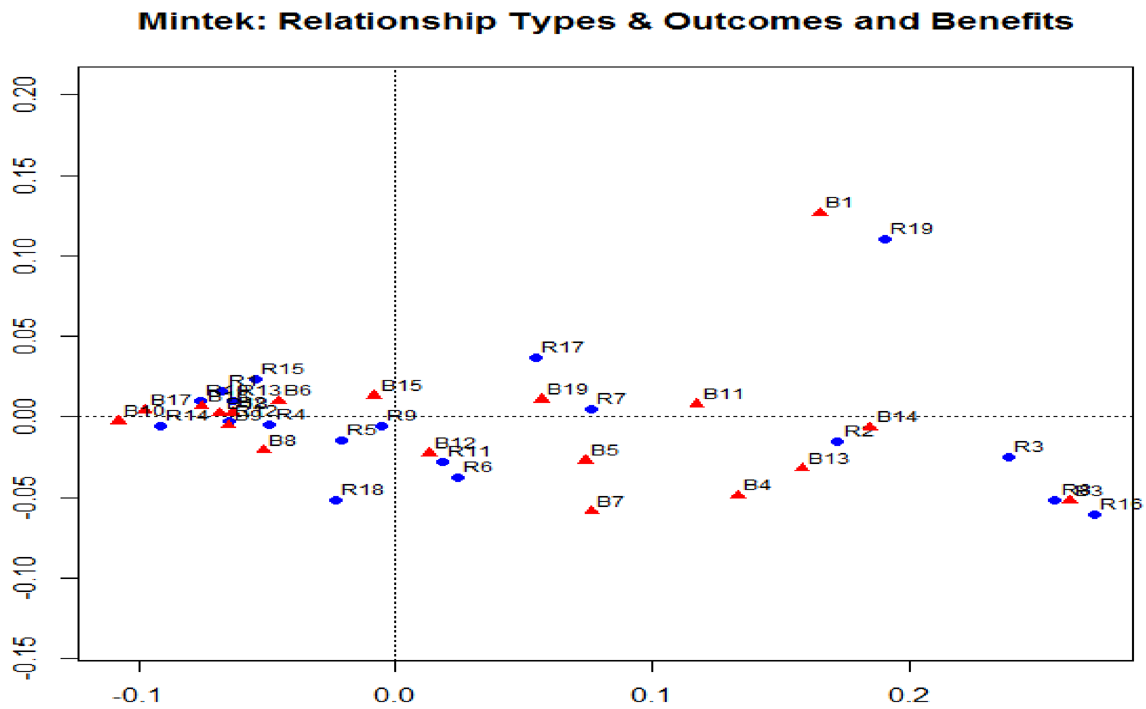
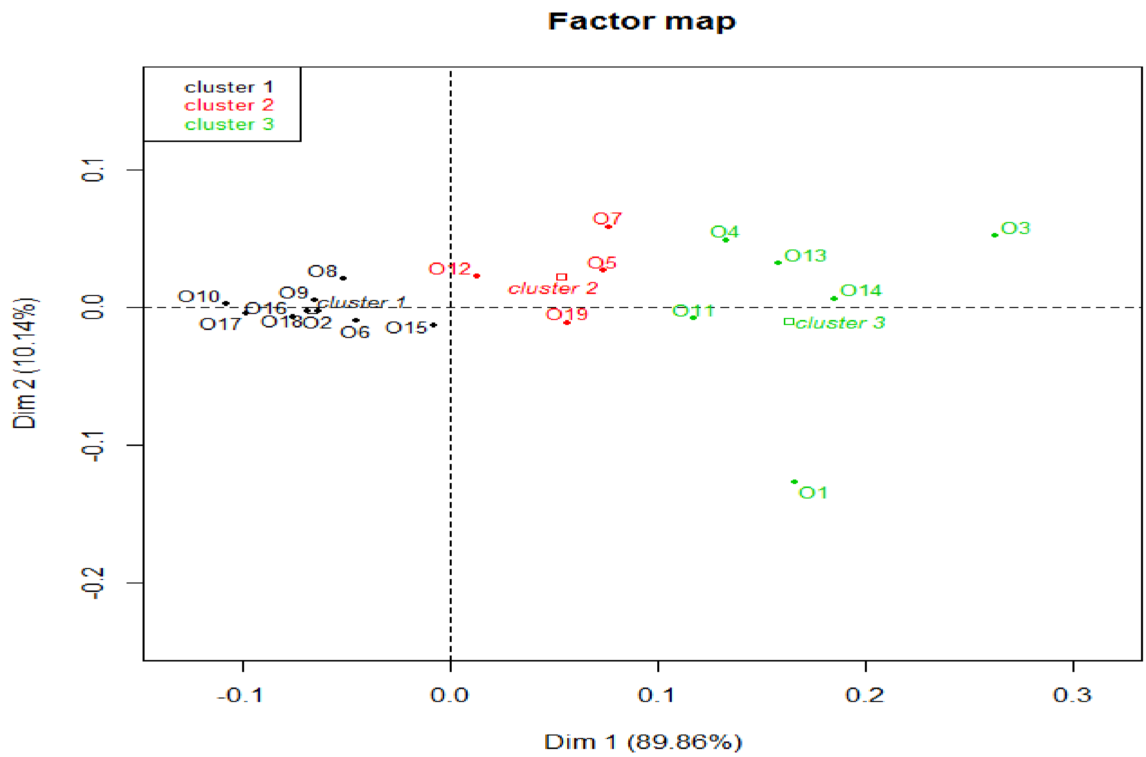


Figure 5.9: Correspondence analysis of Mintek outcomes and benefits



The outcomes and benefits more likely to be produced by the most frequent relationship types are grouped in cluster 1, to the left of the point of origin:

- Participatory research processes (O15), Training and skills development (O6), Improved post-graduate teaching and learning (O2), theoretical and methodological development in a scientific field (O18), scientific and institutional reputation (O17) and novel uses of technologies (O10) are the most likely outcomes and benefits. These are strongly associated with a sub-cluster of economic development oriented relationship types: Education of post-graduate students (R1), Continuing education or professional development (R4), Technology transfer (R13) and Collaborative R&D projects (R15), as well as design and prototyping (R10), Research consultancy (R12) and Contract research (R14).

  This suggests that for a science council like Mintek, contract types of relationship can have positive benefits to enhance their applied research and technology development roles. In universities, contracts are often seen as negative in that they restrict the flows of knowledge by imposing restrictions on who may access data and when.

Cluster 2 reflects benefits and relationships that are strongly associated but further from the point of origin indicating, that they are less common types of outcomes:

- Regional development (O12), Intervention plans and guidelines (O5) and community employment generation (O7) are outcomes and benefits closely associated with monitoring, evaluation and needs assessment (R11) and with policy research, analysis and advice types of relationship (R6).
- Cross-disciplinary knowledge production is an outcome associated with design and testing of new interventions or protocols (B19 and R9). We have seen that these tend to be the interaction with universities.

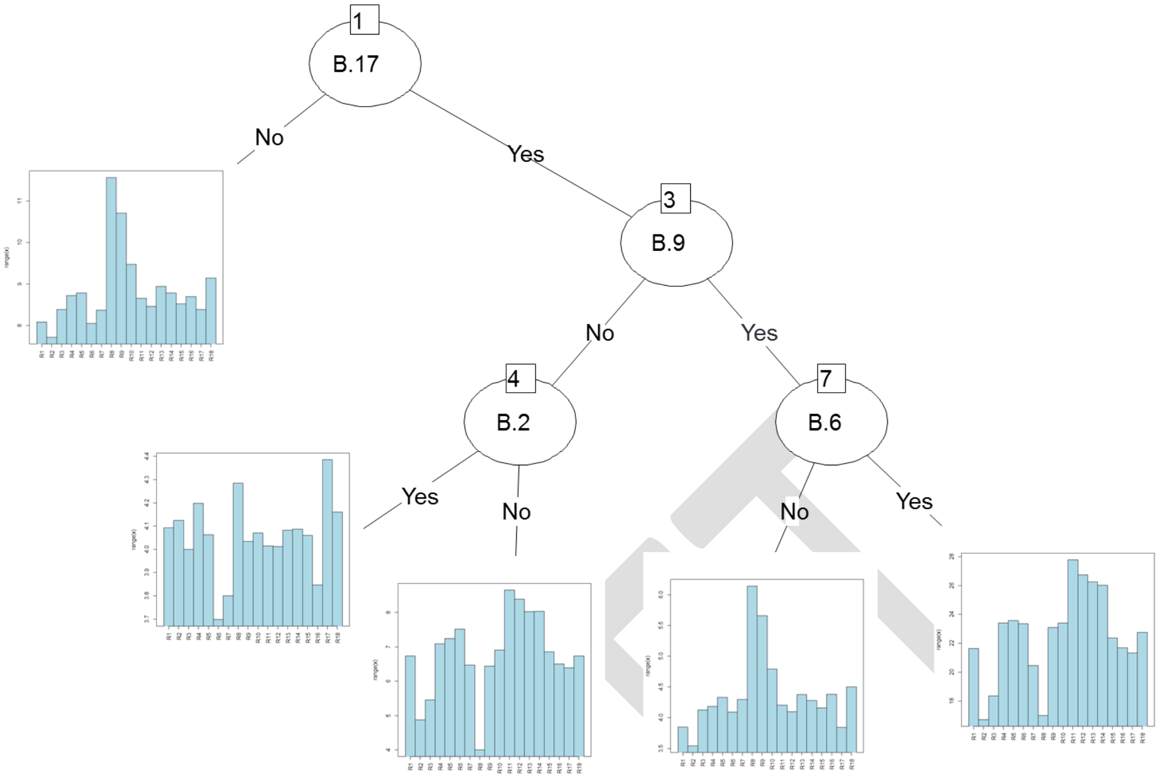
Cluster 3 reflects the less common association between community based research type of relationships and community based campaigns (R8, R16 and B3). Community empowerment and agency (O13) and policy interventions (O4) are more strongly associated with voluntary outreach programmes (R2). A complete outlier on outcomes and benefits is public awareness and advocacy (O1), reflecting the proprietary nature of much of Mintek's interaction with large mining firms and MNCs. As one specialist reported:

> All of my research projects have been with commercial partners, and the details are confidential. The focus has been the development and implementation of leaching and bioleaching process for the extraction of metals from ores.

Benefit to scientific reputation

Analysis using a classification tree yielded a tree with five branches (CP=0.01). The first split was on scientific and institutional reputation (B17). This is significant, in that, for most of the scientists at Mintek, their interaction was perceived to benefit their scientific and institutional reputation, empirically confirming our conceptual proposition.

Figure 5.10: Classification tree of outcomes and benefits



When we examined the relationships that are not likely to enhance reputation (terminal node 2 on figure 5.9), of note, the first variable was ''clinical services'', which as we have seen, is not a common type of relationship for many scientists at Mintek. This was followed by the more applied and market driven types of interaction, design and testing of new interventions, design of new technologies, and joint commercialisation. This may suggest that scientists who are involved in these types of relationships may not be as concerned about their scientific reputations – or at least, they do not see these types of relationship as benefit to their reputations.

Reflecting the importance of firm partners, the next split is 'firm productivity and competitiveness' (B9) as a benefit of interaction. For those who do report firm productivity as an outcome of their interaction, a further split occurs on the benefit of training and skills development (B6). For those who do not report firm productivity, the next split is on improved 'teaching and learning' as a benefit (B2). For those who do report improved teaching and learning (terminal node 5), as we may expect, the main types of relationship that lead to this benefit are participatory research networks, clinical services and continuing education or professional development – and we have seen that these tend to be in partnership with universities. Some Mintek scientists clearly acknowledge and value their contribution to develop national scientific capacity.

In contrast, those who do not report this benefit (terminal node 6), are most likely to interact through M&E and needs assessment, consultancy, technology transfer and contract research. Those who report scientific reputation, firm productivity and competitiveness and training and skills development as their main benefits are most likely to interact through these four types of relationship as well (terminal node 9). What is significant is that these are the main modes of interaction at Mintek, reflecting their applied and strategic research orientation, and reportedly leading to beneficial outcomes for the university and firm partners, and the Mintek scientists themselves.

Conclusion

Mintek as a public research institute has a clear balance of organisational objectives to address national priorities and the three-fold mandate of science councils supported by its strong matrix internal organisational structure and external interface mechanisms.

The pattern of interaction is fairly homogenous, with three clear clusters that respond to its mandate with varying degrees of prioritisation. The predominant cluster of interaction is in response to the national economic development mandate, with large firm partners and universities, and taking the forms of collaborative R&D, contracts, consultancy, needs assessments and technology transfer, for new or improved processes and products, but seen to enhance scientific reputations. There is a significant scale of interaction with other knowledge users that tend to take more collaborative forms and lead to traditional academic outputs and reputations. There is nuance within this cluster, for example, a very small niche of downstream, beneficiation-oriented research and development related to health applications of minerals can be highlighted.

A second smaller cluster reflects a significant emergent niche of interaction, addressing imperatives to support small scale miners and communities to promote livelihoods and regional economic development, in networks with local government and other development agencies. There is also evidence of a third, more philanthropically oriented cluster of activities with communities, responding to social programmes, and taking the form of corporate social responsibility activities, related largely to a role in education and skills development.

Outputs of interaction are more likely to take the form of reports than academic publications, suggesting that scientific excellence and global reputations may not be as strongly prioritised in practice as national and organisational policy propose.

Chapter 6. As a geological survey it is world class: the Council for Geoscience

Introduction

While the CSIR is usually cited as the oldest science council in South Africa, the Council for Geoscience (CGS) has a longer history that can be traced back to the late nineteenth century. It is one of the mission-centred, sector-specific councils reporting to a line department, in this case, directly to the Department of Minerals and Resources (DMR). The CGS provides "important support to government (seismic monitoring, land-use and geological data, shore-line erosion, etc) and provides data to allow innovation in the mining, minerals and engineering sectors (mineral exploration, land and water use, etc)" (SETI Review 1998:8). It is one of the smaller science councils, with approximately 140 scientists in 2013.

The CGS as an organization has grappled with the new policy expectations placed on science councils and the multiple roles they are mandated to play in the national system of innovation. Given the nature of its core research activity – mapping, monitoring, measuring mineral and natural resources and hazards – its main outputs are data collections, basic research reports, and technical reports or services to inform strategic business or environmental or social planning decisions. The main value-add depends on the maintenance of geological databases and maps over extended periods of time, which requires sustained public funding.

The CGS has been criticized by external reviewers for over-emphasizing its statutory 'data collection' role at the expense of its roles in relation to a more viable commercialization strategy, of contributing to knowledge generation and production of a new generation of scientists, and of conducting research to address government developmental priorities. The organization is grappling to balance and manage these multiple roles in a financially constrained environment. These dynamics shape its interaction with external partners.

This chapter begins by providing a historical overview of the CGS, showing how it has faced multiple expectations and pressure to adapt to a new policy environment. The next section describes the core and variable mandates of the organization, and goes on to show how key managers in the organization currently interpret the financial imperatives and contract research pressures as potentially conflicting with its core statutory mandate. The third section describes the minimal interface mechanisms that support cooperation across units, and the unstructured, largely informal external interface mechanisms that facilitate interaction with external partners. The fourth section draws on the survey of scientists to map the patterns of interaction that result in this organizational context.

Historical overview of the CGS

The CGS was legislatively established as a science council in 1993, through the Geoscience Act (Act No. 100 of 1993). It is thus part of the third wave of formation of science councils in South Africa, from the early 1990s. However, it is in fact the legal successor of the Geological Survey of South Africa, which in turn, was created in 1912 through the merger of three Surveys, the oldest of these being the Geological Commission of the Cape of Good Hope of 1898 (www.geoscience.org.za). Its origins lie in the first wave of formation of scientific institutions in South Africa, in the colonial period. This core scientific focus on geological surveys is critical to understanding the mandate and role of CGS as a science council as it evolved over time.

CGS in a shifting policy landscape from 1998

At the time of the 1998 SETI Review, the CGS was assessed as offering a "*world class survey*", which highlighted a distinctive knowledge function and role in the national system of innovation:

> It is regarded as providing a core, pivotal and valued service in the *precompetitive domain*. As a geological survey it is world class. It strives to maintain a systematic approach to mapping and associated research, consistency in approach and presentation of data, retention of data for later re-use and more interpretation, maintenance of a team of credible experts, unquestioned quality of output and timely provision of useful information. *The CGS could be considered a National Facility, mainly collating and providing systematic and routine information, rather than a traditional SET with expectations for a high content of research and innovation* (SETI Review 1998: 8 emphasis added).

At that stage, the core grant of the council was R65 million (80% of its total budget). The core functions of the council were funded by government, with other specific projects for the public sector funded through *ad-hoc* contracts. Two distinctive features are highlighted here - the involvement in the precompetitive research space, of fundamental geological research and mapping surveys, and the suggestion that the council is more of a national facility rather than a science council, with multiple roles.

The 1998 SETI Review panel recommendation was that CGS should be reconfigured as a *National Facility.* Nevertheless, reviewers were concerned with a number of weaknesses within the CGS and recommended changes that reflect the general criteria for *science councils* at the time - the need to make the work program more strategic; to promote interaction with universities, stakeholders and the public; to offer support to small-scale mining initiatives; and to decide on an appropriate balance of foreign versus national needs; as well as to develop a commercialization policy. Management changes were proposed to strengthen the organization, to improve marketing and to improve external linkages and liaison with 'key customer groups' (SETI Review 1998).

Therefore, the new policy environment, with the emphasis on science councils as role players in the national system of innovation, was likely to raise considerable challenges for a knowledge organisation like the CGS.

Raising concerns to counteract the impact of contract work: the 2003 SETI Review of the CGS

The international review of the CGS in 2003 reflected an organisation grappling to manage these challenges. The Review panel found that while the organisation continued to be a world-class geological survey, there were now major concerns that could threaten this position. A set of critical issues that impacted on the scientific status and required urgent attention were identified: recommendations to publish in international scientific journals, link with universities to collaborate on joint projects, upgrade conditions of employment to attract and retain skilled staff, ensure a larger cohort of experts working in the international arena, improve competency in mapping and missing areas such as remote sensing, improve quality assurance of scientific results and methodologies, and acquire ISO certification.

Second, it was recommended that the 'counter-productive effect of contract work'' on the statutory programme should be reduced, by developing a project management approach that would lead staff to prioritise both equally, by enhancing the strategic importance of the annually agreed programme of work with the DMR, by instituting full-cost recovery and transparent accounting practices, and by providing a funding buffer to allow for the variability of contract work.

Other organisational weaknesses were identified and detailed recommendations made, in relation to strengthening the performance management system, greater commitment to transformation imperatives, enhanced strategic marketing of the CGS, clarification of the contractual relationship with the DMR, improving the effectiveness of the Management Board, and clarification of the organisational structure and lines of accountability.

This review highlighted the dual imperatives driving the organisational mandate, and the resultant impact on scientific quality – a recurring theme to the present day. The other concerns highlight the difficulty the organisation was experiencing in developing effective governance, management and operations to respond proactively in the new policy environment.

Ten years later: CGS at the time of the 2009 Review

The 2009 Review of the CGS found that the organisation continued to offer a world-class facility, that it had responded positively to the recommendations of previous reviews, but that urgent issues remained to be addressed, notably, 'to restore its ability to function optimally as a publicly funded national *Science Council*'. Any suggestion that it was more suited to become a national facility had been dropped. The criteria on which the recommendations were based reflected the general mandate of science councils, and did not take into account the specific mandate of the CGS:

> The need for the CGS to position itself as an institution with a major role in providing earth science solutions to areas of social relevance in addition to the more traditional areas of economic (minerals sector) relevance (2009: 4).

Areas of national policy priority that were identified as gaps not addressed in the portfolio of projects undertaken by the CGS now expanded to include poverty alleviation, the energy crisis, human settlements and urban planning. The panel recognised that to address these gaps would require changes in the management structure, and significantly, a review of the funding model was recommended. At that stage, the CGS was under pressure from a shifting, and growing, mandate. It faced an imperative to increase contract income and become more socially responsive, in addition to its traditionally mandated knowledge function to provide earth-science solutions. The review panel acknowledged distinctive and potentially contradictory features that needed to be taken into account in relation to its funding in the national policy landscape:

> …in contrast to other science councils, it has a mandate to deliver certain basic geological information from its core grant; the need to invest more resources in the non-traditional but other societal relevant areas that have emerged since the promulgation of the GeoScience Act; functions of the CGS cut across the domains of several other government departments; the vast geologically uncharted areas of the sea floor underlying the expanded territorial waters of the country (CGS 2009:4).

The panel recommended that CGS should work more closely with the Department of Science and Technology, including representation on its Board, given DSTs role as 'custodian' of the NSI.

The review panel proposed that CGS needed to improve the present levels of dissemination of outputs, and that this would require 'new innovative value-added dimensions in support of broader outcomes in both traditional and non-traditional markets' (SETI Review 2009: 6). An inter-related imperative is to build interaction with external partners, in which regard the panel recommended the elaboration of CGS roles to include:

- Government departments: particularly Water Affairs in relation to groundwater science, but also dti, DEAT, DoA, Housing and Land Affairs
- Private sector: junior mining sector and private geoscience consultants
- Universities: staff exchange, joint projects, training programmes for graduate students, large collaborative programmes

- Other science councils and SoEs: Mintek and ARC collaboration, Energy, including nuclear
- DST: Grand Challenges, science diplomacy in Africa

In general then, the 2009 Review can be interpreted as an attempt to draw the CGS more tightly into the national system of innovation in line with the policy priorities of DST for science councils, and to extend its mandate to be more multi-sectoral rather than sector specific.

Shifts, Changes, Challenges

What is most distinctive about the CGS's role in the national system of innovation over the past five years however, is that it is an organisation with severe financial challenges, a direct result of the global economic crisis and reduced government funding. The critical question to be raised, of course, is the ability of the organisation to adapt and respond creatively to these challenges, which equally affect other science councils like Mintek and CSIR, but perhaps to varying degrees.

In its 2010 annual report, the CGS lamented that:

> … the 2009/10 reporting period has seen the full force of the drastic curtailment of mineral exploration, but, more pervasively, the reduction of activities across many sectors in the economy, such as energy, the environment and certain aspects of infrastructural build. For example, the sudden withdrawal of Eskom as a client, owing to economic considerations, was a big blow to the organisation. This, along with a strengthening of the Rand and the extremely slow repayment for geoservices from some of our international clients, aggravated the income and cash flow of the organisation (CGS 2009/10 Annual Report 2010: 6).

To improve the situation, the organisation initiated negotiations with Eskom, and submitted several large international tenders (CGS 2009/10 Annual Report 2010: 6). This did not materialise in the immediate period as was hoped. The subsequent annual report noted an even more challenging year,

> ... mostly fueled through a strained financial situation that permeated into the very fabric of the organisation. The global financial crisis caused many of the traditional clients of the organisation to cut their budgets over multiple years. As a consequence, the Council for Geoscience carried the full force of a significant decrease in income... To combat this, the Management Board and the Executive Management of the [CGS] developed and implemented short-term strategies within a short time period to protect the organisation

> and its staff from further losses. To ensure the long-term sustainability of the organisation, direct costs were reduced to a minimum, which included the suspension of geoscience library budget, the termination of the printing of maps and other [CGS] publications and a suspension of new appointments, including bursars that had obtained their degrees during this period (CGS 2010/11 Annual Report 2011: 6).

Some would argue that such cost-cutting measures indicate an element of short-sightedness that limit the organisation's capacity to be responsive and grow in the medium term.

However, senior management pointed out that the nature of the financial challenges is directly related to its specific type of knowledge role, and the fact that it operates in a 'negative revenue pool' (Gadiesh and Gilbert 1998). CGS operates at the beginning and end phases of a value chain, where there is high risk and little positive commercial value. For example, in the mining value chain (see Vorster 2001, Deloitte 2012), the CGS operates in the pre-competitive space. Mining companies rely on geoscience research and mapping in the form of government funded geological surveys even prior to the phase of exploration and assessment to determine the feasibility of mining a deposit (which the CGS may then contribute to in the form of a consultancy). Similarly, post-mining environmental rehabilitation activities, typically informed by government funded geological surveys, are also excluded as important activities after the closure of a mine (see Cottard 2013).

These economic dynamics have driven dependence on government and/or donor funding for geoscience research globally (see Findlay 1992, Duke 2010). In fact, the financial pressures experienced by the CGS are not isolated to South Africa. An international conference of geological surveys in 1992 called for global collaboration and networks, in the face of their changing roles:

> Beset by shrinking operating resources and critical scrutiny over the relevance of traditional programs, these surveys face increasing pressurs to respond more effectively to the current needs of society. These needs are driving surveys to provide leadership in the application of geoscience knowledge, in order to address social and environmental questions, as well as in the more traditional applications to resource development (Findlay, 1992: 109).

In this context, the attempts by CGS management to find sources of external income must be interpreted. In its 2011/12 annual report, the CGS management reported that the austerity cuts had the desired impact on stabilising the organisation:

> While the temporary suspension of parts of the Annual Technical Programme resulted in a reduced statutory programme, the Board and Management are pleased to report that, despite the financial difficulties of the organisation, the technical performance of the Council for Geoscience for the past year was 95,4 per cent, which testifies to the dedication of its staff and the sound management of the organisation (CGS 2011/12 Annual Report 2012: 7).

During this period, opportunities grew for public funding of geoscience-related projects, both nationally and internationally.[7] A recent shift has been a system of competitive "agency" funding allocated by DST and DMR, to conduct priority projects such as acid mine drainage or mine rehabilitation, which it was reported, 'far exceeds our baseline but at least that is now allowing us to focus our resources back in South Africa and train some of our younger staff' (Interview with senior manager 5, 2013). Similarly, proposals are submitted to Treasury under the Medium Term Expenditure Framework in relation to national priorities such as shale gas.

The current pathway of the CGS has been shaped in important ways by these factors. Research activities and interaction have been shaped largely in response to managing financial challenges, and attempting to implement an elaborated and extended organisational mandate. The following sections examine the changing formal mandate of the CGS, against this context.

The shifting mandate and strategic objectives in tension

The principal fixed mandate for the CGS is set out in the Geoscience Act (1993), which prescribes that the objective is 'to promote the search for, and exploitation of any mineral in the Republic, to undertake research in the field of geoscience and to furnish specialist geoscientific services' (cited in the CGS Strategic Plan 2012-17: 5).

Fixed and variable legislative mandates

The constitutional mandate of the CGS is found in sections 24 and 26 of the National Constitution. The CGS operates under three types of mandates (some are fixed and others are varied). The principal (fixed) mandate of the CGS is to develop and publish world-class geoscience knowledge products and to render geoscience-related services to the public and industry (CGS Strategic Plan 2012-17). It is not different from other science councils in this regard, in the emphasis on knowledge generation and the scientific role. The second, varied mandate relates to CGS's role in the National System of Innovation as prescribed in the National Research and Development Strategy (2002) and

[7] The organisation reported the submission of twenty-one large tenders, all in excess of R1 million. At the time of writing the 2011/12 annual report, three new contracts had been awarded, one was cancelled and for nine tenders, they were awaiting a decision

the White Paper on Science and Technology of 1996. This mandate states that the CGS 'has an obligation to carry out specific functions as may be determined from time to time by the relevant Executing Authorities, as long as these do not conflict with the core mandate as articulated in the Geoscience Acts' (CGS Strategic plan 2012-17: 8). Here, too, it is not different from other South African science councils. The third (varied) mandate of the CGS is systematically to develop and maintain the national geosciences knowledge infrastructure for the onshore (land) and offshore (oceans) environment of SA (www.geoscience.org.za). Here it does differ from other science councils, in its role as a national facility.

An amendment to the Geoscience Act in 2010 extended the legislative mandate to include advisory services in relation to geohazards and geo-environmental pollution, as well as mandating CGS to "act as custodian for all geoscience information'' (Annual Report 2012). A task team was established to determine the organisational changes required (Strategic plan 2012-17). This is akin to the MRC's role as custodian of national health research. It relates to the CGS role in contributing to enhance the quality of life of citizens.

The CGS currently defines its mandate in terms of seven imperatives as found in the Acts, which it seeks to follow and uses to guide its activities (CGS Strategic Plan 2012-17:6-7). The starting point for all CGS strategic planning remains this legislative mandate, presented verbatim in Box 6.1 below.

Box 6 .1. The CGS legislative mandate

- The systematic reconnaissance and documentation of the geology of the earth's surface and continental crust, including all offshore areas within the territorial boundaries of South Africa.
- The compilation of all geoscience data and information, particularly the geological, geophysical, geochemical and engineering-geological data in the form of maps and documents, which are placed in the public domain.
- Basic geoscience research into the nature and origin of rocks, ores, minerals, formations, the history and evolution of life and the formation of the earth, with a view to understanding the geological processes of both the past and present and to compile and publish such research findings nationally and internationally to contribute to the understanding of the earth, its evolution and its resources.
- The collection and curation of all geoscience data and knowledge on South Africa in the National Geoscience Repository. This repository houses a large and growing collection of geoscience information on all countries of the African continent. This information also includes data that were received from mining companies, universities and research institutions worldwide. Public access to all geoscience information is subject to existing legislation, arranged through the mandate of the CGS.

- The rendering of geoscience knowledge services and advice to the State to enable informed and scientifically based decisions on the use of the earth's surface and the earth's resources, within the territory of South Africa.
- The management of a number of national geoscience facilities on behalf of the country. These include the National Seismograph Network, the National Borehole-Core Repository, the National Geoscience Heritage Collections (Geoscience Museum), and the National Geoscience Library. As part of its seismological monitoring function, the CGS contributes to the verification of global compliance to the ban on underground, underwater and upper atmospheric nuclear explosions in terms of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) by making available the data from stations located on South African territory.
- The rendering of commercial geoscience services and products to national and international clients.

Source: CGS Strategic Plan 2012-17

It is evident that the legislated mandate emphasises the scientific roles, and mapping and data collection functions primarily, and the new environmental mandate focused on the public good. In contrast, most of the recommendations made by the 1998 SETI Review and the 2009 Review panel related to the seventh imperative: "rendering *commercial*l services and products to national and international *clients*".

Subsequent organisational reports reflect attempts to address the concerns of the SETI reviewers, given the phases of the value chain to which CGS typically can contribute. Table 6.1 below provides an overview of key CGS projects in 2011 and 2012, relative to the legislative mandate, and identifies the partners or funders of projects.

Table 6.1: Key CGS Projects 2011/2012

Legislated mandate	Project	Funders and partners
Management of GeoScience facilities	*National GeoScience Repository* (all countries of African continent) National Seismograph Network Infrasound Observatory National Borehole Core Repository National GeoScience Museum National GeoScience Library South African Minerals Database	Annual Technical Programme – fixed, statutory mandate
Compilation of geoscience data and information to inform maps and documents	Atlas on Geological storage of carbon dioxide in South Africa (Zululand and Algoa Basin assessment)	Zululand Basin funded by UK Department of Environment and Climate Change; Algoa Basin funded by EuropeAid (collaboration with British Geological Survey, Netherlands Organisation for Applied Scientific Research, local law firm)

Render services to the State to enable decision on use of earths surface and resources	Strategic Water Management Project (environmental impacts of mining activities) Olifants and Komati-Crocodile River catchment areas Report and database on coal resources and reserves Industrial minerals inventory for South Africa Identification of rare-earth element deposits in South Africa EO MINERS earth observation monitoring environmental and social impact of mining in Mpumulanga South African Geological Hazards Observation system Electrical and hydraulic properties of acquifiers Centurion Geohazard risk map (propensity for sinkhole formation to guide safe development)	Department of Mineral Resources and inter-governmental Task Team on Acid Mine Drainage EU Seventh Framework programme Department of Science and Technology to create a geological hazard atlas of SA using remote sensing techniques, including post-graduate students Funded by NRF in collaboration with Italian collaborators City of Tshwane Metropolitan municipality
Seismological monitoring	Monitoring global compliance to Comprehensive Nuclear Test Ban Treaty from national stations Constructed seismograph stations and data centre in Klerksdorp-Orkney- Stilfontein-Hartbeesfontein region to expand *National Seismograph Network* Probabilistic Seismic Hazard Analysis for proposed nuclear site at Thyspunt	Locations and data available to DMR

Provide geoscience data and services to external clients nationally and internationally	Sedimentary mapping and exploration for coal reserves in Mozambique	Rio Tinto
Systematic reconnaissance and documentation of geology of earths service and continental crust including all offshore areas	Mozambique Mapping project (processes of continental formation in Mozambique and Antartica) Geohazards along the coastline of South Africa	 University of Vermont (USA)

Source: Compiled by authors from CGS annual reports and organizational documents

Current strategic objectives

In 2011, the CGS undertook an internal strategic planning process with Board, DST and DMR participation, to develop a new five year strategic plan for the period 2012-2017, in response to national imperatives and DMR outcomes. These objectives are used to drive current performance monitoring for the organisation and individual scientists. The five year strategic plan noted that the business model is designed to address national priorities, such as development of the first economy, rural development and poverty eradication, innovation, Africa development, and skills development, as well as other mandates within the NSI and government strategic policy (Box 6.2).

Box 6 .2. National imperatives driving the CGS business plan

- Growth and expansion of the CGS and development of the 'first economy' (i.e. ensuring that the CGS grows as an organisation and also contributes to economic development – that people, science and finance);
- Regulatory, systems and stakeholder (ensuring CGS compliance with legislative requirements, development of CGS regulatory systems, and alignment with national mandates);
- Rural development and poverty eradication (ensuring that the CGS contributes to the development of the second economy);
- Innovation (development of products, systems and services);
- Africa development (CGS assistance in the development of Africa and its people by upgrading geoscience infrastructure of the continent);
- Skills development (building capacity in respect of scientific, administrative and managerial/leadership skills); and
- Transformation (business and people)

Source: CGS Strategic Plan 2012-17

"The parliamentary grant is enough to pay our salaries. We cannot do much with it"[8]

There is, however, tension between the ideal conceptualization of how the CGS should operate, and how it actually operates in response to these mandates. The organisation appears to struggle to respond to the new funding environment and multiple policy expectations. While it is supposed to fulfill its fixed and varied mandates, and expected to respond to the needs of the country, CGS is

[8] Interview with CGS senior manager 1 2013

unable to do so and at time, has laid more emphasis on the varied mandates at the expense of the fixed mandate. The major reason provided by senior management interviewed is the funding model. Due to major reductions in the parliamentary grant, which has fluctuated as low as 30%-50% of total income, CGS has been driven to pursue 'commercial' work (i.e. consultancy), chiefly outside of the country, to the detriment, at times, both of their scientific contribution to knowledge and to the South African NSI (2011/12 CGS Annual Report).

Senior managers argued emphatically that the parliamentary grant is insufficient to enable them to fulfill their statutory mandate, in contrast to earlier periods before 1994, in which they were fully funded by government. The CGS is increasingly in a position where it has to fund its statutory functions through its commercial work.

> Well I know that we've got a role to play but the situation is such that we don't have the kind of money that we can really, fully go into innovative projects and stuff. Let me just give you the background, Council for Geoscience needs to source a lot of income from commercial work to be able to fund a lot of its statutory functions, because the budgets that we get from government, the parliamentary grant barely covers our salaries. So it's a difficult question, of course we should be involved in stuff like this, but since we not fully funded, it makes things very difficult… (Interview with senior manager 4, 2013).

These financial imperatives have strongly shaped CGS's recent trajectory, which has resulted in a mismatch between the national scientific service the organisation intends to offer, and what it actually does. A senior manager explained the negative effect of the pressure to earn external income:

> I am not sure if other councils have this problem, where we start having conflict between trying to earn extra money (and this is now a serious problem we have, we notice distinctly that research suffers) and trying to conduct research. We are forced to concentrate on bringing in the money rather, that becomes an issue on its own, and also when there is pressure on you, you are less likely to be more innovative (Interview with senior manager 7, 2013).

Such experiences echo that of the CSIR in the 1990s and early 2000s, when staff critiqued the impact of private sector drivers on the research agenda. The 2009 SETI Review panel warned against 'opportunistic' commercial decisions, and proposed that even contracts should add to the ''development and growth of the knowledge base in support of the mandated function'' (2009:8). The distinctive nature of the CGS, and the extensive costs of the maintenance of national repositories over time, mean that the financial imperatives are in tension with their fixed scientific mandate. So much so that within units, there were reports of a distinction and separation between '*people that are mainly on statutory work and others that work only on commercial projects', and the need to balance these out so that commercial projects also have research* value (Interview with senior manager 7, 2013).

In practice therefore, the CGS tends to operate mainly outside of South Africa, in relation to foreign clients or donors. Examples cited are tenders that were won for mapping projects in Uganda, Tanzania, Rwanda, Namibia, funded by World Bank or European agencies and future projects in Sudan and South Sudan, Qatar, Malawi and so on. This thrust was driven by the need to raise funds, and a perception that there was little support from government in South Africa:

> It was a huge frustration, to the extreme where we said, let's just give up on what we do in South Africa, we are just not making any impression, we have prepared submission after submission and we are getting nowhere. That took lots of our resources out of South Africa. There was a time when we had teams of people … in Mozambique, Papua New Guinea, Ghana, Algeria, Morocco…. Now you can see South Africa suddenly was left behind. But we had no choice, because in 2005 we had a situation that if we could not come up with exactly the same level of funding that we were getting from government, we could not keep going as this organisation…(Interview with senior manager 5, 2013).

> My unit is actually involved in geological mapping in Tanzania at the moment. We did mapping in Uganda, in Rwanda in the last 2-3 years - we finished mapping in Rwanda in this year. And we tender for our jobs from outside of South Africa, like mapping in other countries which are mainly funded through the World Bank or European agencies, like that. So we try to raise funding through various commercial projects, remember once I mentioned ones like mapping in other countries?..." (Interview with senior manager 4, 2013)

> …Right now I have geologists in Tanzania and in Namibia and very soon I hope we'll have a project in Sudan and that's the interest DIRCO is Khartoum and South Sudan in particular. So there I'm a bit more what shall call it, the political planning arena because there's reasons why South Africa would like to have a stake in South Sudan and [DIRCO] is trying to set up a delegation to go to Qatar, because Qatar may want to fund this project in South Sudan at least. Then I'm also going to Malawi because we also looking at a project quite a large project in Malawi we've just finished projects in Rwanda and Uganda." (Interview with senior manager 2, 2013)

Some senior managers interviewed argued that by default, the CGS has neglected its domestic imperatives. So much so that the CGS, as a senior manager puts it, needs *‘to work a lot on becoming a household name like CSIR, I mean everybody knows the CSIR, but nobody knows us [in South Africa]*’ (Interview with senior manager 7, 2013).

While science councils generally, and the CGS specifically, are meant to be forerunners in innovative research, the problem of funding at CGS has meant that this crucial aspect of their mandate suffers:

> I'm not quite sure about the science councils, if they in the same boat as us; basically it’s through the research arm really of the government trying to be up to date or in the forerunners of research, forerunners of the latest technology and research, that’s what I think of the science councils. For the CGS itself, it’s a bit of a confusing one, because I'm not sure if all councils have this problem, where we starting having conflict with trying to earn extra money, and this now is a serious problem we have, now you notice distinctly that the research suffers, because now we have to, we are forced to concentrate on bringing in money rather, so that becomes an issue, and also when there’s pressure on you, you less likely to be more innovative, you know when there’s pressure on you to bring in money. (Interview with senior manager 7, 2013).

Funding challenges impact on research quality, for example, in terms of the inability to replace aging research infrastructure and laboratories:

> As result of that, we end up going to China, Japan, Canada, Australia to have our samples analysed and that costs a lot of money going to those places (Interview with senior manager 6, 2013).

This means that national scientific capacity is not being sustained or built up.

Moreover, the contradictory policy space and the primacy of financial drivers mean that addressing government’s developmental imperatives could remain aspirational in the CGS’s research activities. CGS’s managers’ understanding is that the organisation’s role is sometimes thwarted by the very government structures which are meant to enable it. For example, one of the senior managers reflected the challenge to balance and prioritise competing demands:

> I think we are there to be leaders within the country, we do have a governing mandate and we are there to be a source of information or advice or whatever between the role players, which obviously might directly be our departments, but ultimately government as a whole. But for us a specific one when it comes to Geoscience, we have a strictly defined mandate

really, so we do feel that research is core but it's probably the aspects that are struggling the most - funding will be one of the aspects. But we need to aim to actually get back to the research fundamentals because if we lose it and we lose that capacity - I mean I'm into training youngsters and if they don't get trained into research in 10 years' time the guys won't be doing research... You also need fundamental research that's relevant to South Africa. But if it's part of international, it's fine as well because that's what science is, we are part of the scientific community of the broader law. It doesn't mean everybody can do exactly what they want, that's the other extreme, so we got this balance between, but it has to be relevant research (Interview with senior manager 6, 2013).

Highlighting the need for science councils to perform applied research, which would ultimately assist in addressing concrete problems in the country, a senior manager argued:

I think science councils, what they should be doing is sort of research in a more applied sense that will fill the gap where we need to in the country develop or we have to embark on national programmes and we don't necessarily have all the know-how, all the tools, I think this is where science council should come in beyond your universities, which I think focus more on the academic research, the more blue sky research, science council should be a lot more focused... (Interview with senior manager 5, 2013).

In sum, the CGS management interviews reflected a lack of ability to respond dynamically and strategically to a changed policy and funding environment. While there is apparent compliance with national imperatives evident in formal organisational documents, management was not able to be enterprising and identify strategic opportunities within South Africa that simultaneously bring in funding and address national priorities. Partly this is related to their fixed mandate, to the core nature of their work in maintaining historical geoscience collections and surveys, which requires sustained public funding over time. Partly, it seems, it may be related to a lack of organisational interface structures and mechanisms, the focus of the following section.

A traditional organisational structure

The CEO is assisted by a Management Team of three Executive Managers. Business Units, each headed by a Manager, are responsible for the day-to-day activities and core-functions of the CGS (www.geoscience.org.za [accessed 22/05/13]).

Strategic research priorities are based on six scientific thrusts, and these reflect the focus and expertise of the business units:

- Geoscience mapping
- Minerals development
- Environmental geoscience and chemical geohazards
- Engineering geoscience and physical geohazards
- Water resource assessment and protection
- Energy geoscience

Significantly, the CGS is a geographically dispersed organisation, with offices spread across six provinces. The Central Regions unit based in Pretoria is tasked with geological mapping in three other provinces besides Gauteng: Free State, Mpumalanga and North West. The other offices are located per province, in the Eastern Cape, KwaZulu Natal, Limpopo, Northern Cape and Western Cape.

At the time of research, the CGS had six main divisions, three research related, two business functions related, and one strategic functions related (Figure 6.1 below).

Figure 6.1: Six main divisions at CGS

Strategic planning and monitoring as an internal interface structure

At the time of research, the CGS had an organisational culture characterized by a high degree of scientific autonomy. Units were responsible for winning funding and conducting research or mapping, and the CEO's office was responsible for coordinating information to report to the board against strategic priorities. The centralised unit responsible for coordination within the organisation was the Strategic Planning Unit, a single person directly reporting to the CEO. This unit is responsible for the strategic planning of activities, and as such, its head is integrated with all the unit managers. All the information required for planning is obtained through the unit heads. The main role of this central unit at the time of research, therefore, was operational coordination and planning, to address and report against the strategic plan, the annual performance plan and the annual technical programme. In practice, it seems the business units had a great deal of autonomy:

> I do not communicate on an operational level. I don't interfere in their management of units or anything. All I need from them is just information. Okay, so I'm not involved in any projects with them, or any other stuff, just the planning part. The execution part, they are responsible for, the unit managers, they need to see that their people or the unit delivers on their projects and their programmes (Interview with senior manager 4, 2013).

Some scientists reported strong interaction across units in practice, within the organisation:

> When I do a mapping of a particular area, we look at the economic geology of that area to understand the mineral potential, so for that we get the help of the MRD people. Then we give information on the hydrology of the area, so we take our water geoscientists with us… and we will also consult with them so that our research product is actually a product of interaction within these units. It's not a single unit activity. It's a combined effort of scientists of various units, we get multidisciplinary. So there is always interaction within CGS (Interview with senior manager 4, 2013).

Units such as Analytical Services, which analyses rocks, minerals, water and industrial materials, by definition will work together with other units. Likewise, the units within the Applied GeoScience division all rely and depend on prior mapping work conducting by units in the Regional Mapping and Scientific Services divisions:

> For example, when we are looking at a particular area for mineral deposits, we need the guys to have gone out there and mapped, having geological maps, and also come with geophysics, geophysical maps which use various techniques magnetic, electromagnetic, radiometric, and also geochemists going out taking samples at the area. Then we are looking at geology, geophysics and geochemistry and also a particular model that we will be looking

> into, and start correlating, eventually ending up with the product. The aim is to come up with the target where we can drill and come up with mineral deposits (Interview with senior manager 6, 2013).

Such internal collaboration is largely an ad hoc unstructured practice, driven and based on individual relationships. The model of a matrix organisation, in which units collaborate on large-scale applied projects is still an aspiration, rather than a reality. As at CSIR, the plans to roll out such a model on a wider scale are based on a pilot process with a state-owned enterprise:

> We are going to focus on that more in the future now, we are going big time into this, where if we get a project, a big one, it will be managed separately from any unit. You will put your team together from all the different units and you will then manage through them, because this, it's a lot of work for these huge projects. We got good experience for this with a project that we are doing for Eskom, and it worked very well (Interview with senior manager 4, 2013).

The limitations of the uncoordinated approach, which can allow the development of "fiefdoms" not aligned with the organisational mandate, was recognized by the Board. Since 2014, a new matrix organizational structure was formalised and implemented, to promote coordination and integration internally.

In sum, for our purposes, much of the project work was unit based and driven by project leaders' expertise and interests, as opposed to being coordinated, aligned or supported organisation-wide in terms of strategic objectives. This is a major problem in light of a 'mid-career skills gap'' in the organisation, which has left only a small cohort of experienced senior scientists (2009 SETI Review: 4). It seems however that the push to have projects coordinated from the centre with scientists from all the units has the potential to benefit from different expertise, and to address this constraint.

External interface structures missing

When asked about interface structures or mechanisms to offer support and promote interaction with external partners, the majority of senior managers interviewed was unaware of any, or claimed there were none.

Some reported that a dedicated business development unit functions to "look for jobs'' and arrange meetings or visits with potential government clients. When prompted, others explained that the business development unit plays a role in marketing the organisation and brokering contracts for what is referred to as the 'commercial'' work. The business development manager may travel to visit countries, or arrange visits by country delegations, to promote the organisation's services, with a stronger marketing function. CGS pays for a service that alerts the organisation to funding opportunities. The business development unit thus serves as a kind of external interface mechanism with limited functions, to network particularly with African governments, to identify opportunities for tenders and funding. The role of the business development unit internally was limited, to support the technical submission of a tender, but thereafter, the business unit is responsible for delivery. Some reported that a contracts office monitors all contracts and MoUs.

> Marketing of the CGS in South Africa, to build its reputation akin to that built up across Africa, was identified as a current strategic priority. An external service provider was engaged to "'elevate' CGS to the right level, not where we seem to be treated as though we are a consultancy, we are a large national facility, and in a way we need to educate our own department to use us better (Interview with senior manager 5, 2013).

Intellectual property interface structures are absent and there is no IP office. Some managers claimed that the CGS does not create IP for private exploitation:

> Our IPs, we are not really making big innovations which can bring in revenue,…it's not a technology driven council, it's trying to understand resources, the geoscience, so that our IP is being protected for the benefit of the country that is shareable (Interview with senior manager 4, 2013).

These managers were of the opinion that if the organization is not funded sufficiently to innovate, there is no need for a contracts or IP office.

Others identified IP as a neglected area at CGS:

> We probably do more on that field than we realize, because we are specialists, especially in the government sphere we are specialists, actually we just don't quantify it. We need to see what we develop in IP and how we can protect it (Interview with senior manager 6, 2013).

It seems that much of the external interaction is based on individual scientific collaboration with peers:

> So in geoscience there is always a lot of interaction….a consulting company providing geoscience mapping and environmental studies, or partnering with the British Geological Survey or we have a consortium, Mintek for geotechnical aspects and the University of

Norway. We have been approached by the Angola government to tender for geological mapping for the whole country in five years, a big consortium with a geological agency in Finland, we form partnerships (Interview with senior manager 4, 2013).

We are a diverse organisation, we can get somebody to do something, you do get these small networks going, but those, they still work on a personal basis (Interview with senior manager 6, 2013).

It was commonly pointed out that 'mapping units' have their own scientific networks and typically source tenders they have identified themselves:

Most of these things also come from the units because of the subjects that they work on, they are the first to become aware of opportunities coming up….We are actually well known in Africa for doing this kind of work and so we are aware when something is coming up, usually those countries will contact us and say, watch out for a tender (Interview with senior manager 4, 2013).

Some of the senior scientists have good international reputations, serve on international bodies and science committees, in extensive global networks, that allow them to win projects and grow the organisation.

Obviously it's the more senior scientists that get into this mode '[of partnerships], as they start mastering their subjects better, they tend to communicate more with people in an adjacent field (Interview with senior manager 5, 2013).

Scientific networks and regional offices as external interface mechanisms

The 2009 SETI review proposed that the CGS should look into the possibility of participating in big research collaboration and training programmes throughout the continent. Such large-scale scientific networks operate as external interface mechanisms, to support interaction with other knowledge partners and governments. These interactions are driven by the nature and focus of specific disciplines. For example, as one unit head explained:

In seismology we have a bit of an advantage over everybody else because this is an international science, so I find we have a lot more international collaborative interaction as opposed to others, because an earthquake can affect across borders, it is not confined to one country, so we get a lot of people contacting us and we contact them, so that has driven us a lots, especially with African countries, they see us as experts in this area… we don't

> have data on seismology in Africa, so that drives the interaction (Interview with senior manager 7, 2013).

CGS has participated in large-scale projects, some funded by European countries or the World Bank throughout the continent:

- the compilation of the SADC hydrological map which was a European-funded project that sought to address the need to standardise groundwater systems in the region (20111/12 Annual Report 2012: 7)

- the Africa Array programme, which seeks to establish a network of geophysical equipment across the African continent, promote the training of African students in geosciences and maintain a workforce of highly trained geoscientists and researchers for Africa (www.geoscience.org.za)
- partnering in the African European Georesources Observation System (AEGOS) project which aims to develop a Pan-African spatial system capable of hosting and providing access to geological information, energy, raw materials and mineral resources.
- provision of direct capacity building support to African Geological Surveys through various programmes and interventions such as seismology training and the provision of technical support (20111/12 Annual Report 2012: 7). Countries which have benefited from this technical training include Botswana, Mozambique, Namibia, Rwanda, Swaziland and Zimbabwe.
- A geological survey of Tanzania, funded by World Bank, involving universities and the British geological survey

Such networks with international stakeholders are usually supported by formal Memoranda of Understanding signed at corporate level, between the main organisations, which represent an important form of external interface mechanism.

The regional offices also function de facto as external interface mechanisms, as they provide the basis for closer integration with provincial priorities and problems: 'we do have the additional function of being of a local service, but we are not confined to the province, our research can be anywhere that fits within the strategy' (Interview with senior manager 6, 2013). The regional offices are responsible for the geological investigations of a region, whether baseline geology or to assess the potential of mineral deposits, or the extent of geohazards. The regional offices are typically small, do not have all the areas of expertise, and tend to work primarily on statutory projects in the province, but also participate in national projects that are centred in their province. The marine geophysics unit is responsible for the offshore environment, particularly in relation to future mineral resources.

In these offices, there is much closer alignment with developmental mandates and public good:

> The thrust is actually benefitting the poor areas… how can we aid the economy (mineral development). Groundwater, in our case, is quite a future issue, on health hazards and things like that. But another agency will have to follow up, the Department of Health, if there's something found. It's not our mandate directly, we are looking at it from the element and the rocks affecting the ground water. Or on the small scale, its brickworks, they want technical assistance which is like 'I've got this area, is this suitable for clays for bricks' and that's where we come in (Interview with senior manager 6, 2013).

The point was made that the advisory role of dealing with such small scale ''clients'' does not lead to high financial returns:

> The services are not free, but it's certainly a lot less than if we were going commercial, because we are willing to do that scale of operation… We are the only sort of government agency type thing that is there…Commercial is another story.. because it's very much on a tender or we deal with consultancies (Interview with senior manager 6, 2013).

The museum also serves as an interface mechanisms, in that it includes a core facility, a repository that offers services to external clients, where

> We keep all the holes that have ever been drilled in South Africa for future reference. Dating and analysis techniques change so you can extract more information. To re-drill a hole at about R2000 per meter is very expensive, where you can go get a sample. Those holes have all been logged, we know exactly where they are, they's been geologically identified so anyone can walk in there and arrange with us to get a sample (Interview with senior manager 5, 2013).

Likewise the CGS manages a repository of soil samples in South Africa. In a similar vein, the Analytical Services unit serves as an external interface structure, in that

> The public has access to us, they come in here with their samples, they want to know is this of any value, can I do anything with it? Or why is this thing breaking? Or why is this happening to this material? It could be the layman who thinks he's got a valuable thing in

> the backyard or municipalities, or industrial companies (Interview with senior manager 5, 2013).

The sale of maps, the library and the museum serve as external interface mechanisms for dissemination of CGS products and expertise to the broad public and geological consultancies. School children are trained in geoscience at the museum, and a schools outreach programme and exhibitions provide the public with scientific information and aim to attract students into geology.

Incentives

A balanced score card system has been adopted to monitor individual performance. Some complained that this was undermined by the separation and imbalance between statutory and commercial work:

> You get certain things to do, targets, and they can be statutory, but if commercial work comes along then that is more important, or at least you have to give priority to the commercial work and those targets need to be met as well. So people will then put the statutory stuff on the backburner and there's a frustration that there's not a clear guideline (Interview with senior manager 5, 2013).

Managers interviewed reported a system of awards to scientists, for example, a monetary award for publishing a publication, to use for conference attendance or to buy equipment. This was suspended due to the recent cost-cutting measures. A controversial system of performance bonuses was in place, but again, curtailed due to financial constraints. An incentive scheme to reward those who build business and bring in significant funding was at draft policy stage.

As always, the issue of incentives aroused a great deal of emotion:

> When you become a scientist you don't do it for the money, you do it for the love, so an incentive should be more something that would excite them and get them more creative and innovative. I think that's probably the reason why that incentive policy never really kicked off because is not actually the driver that the scientist needs (Interview with senior manager 7, 2013).

The issue of reputation, built up by high quality reports and publications acts as inherent reward for scientists. The opportunity to travel and access international scientific networks was identified as one such incentive, as was the intellectual challenge of having the entire range of the geoscience discipline in a single organisation with the opportunity for varied work experiences and environments – "*you can be working in the laboratory now, tomorrow you are out in the field, the* *dater after you are lecturing, you are giving talks, we allow our scientists all of that"* (Interview with senior manager 5, 2013).

The pressure on individual scientists to raise funds was seen as a disincentive, and a cause of resignations:

> Since 2009 we have lost about 43 scientists, mostly because of this thing [chasing money]. Let me go work for a consultancy if this is what I am doing here in any case, why should I be sitting here is a science council? (Interview with senior manager 5, 2013).

In sum, the CGS has not strategically created formal structures to align and coordinate internally, or to support interaction with external partners. The main driver of interaction is the scientific agenda of each unit and its scientific leaders, who build their own highly specialized networks, but driven at the macro-level by the need to source funds. There are important interface mechanisms that do facilitate commercial consultancy relationships and scientific collaborations, but these are ad hoc, rely on individuals and are not harnessed to maximum effect. Since the time of research, the CGS has put in place new strategies to enhance internal coordination and alignment of purpose, such as a stakeholder management plan that identifies key stakeholders for the organization and for specific niche areas (CGS 2014). The next section will shift to analyse the patterns of interaction evident in the practice of scientists across the CGS, in this context.

A world class survey grappling to balance financial and intellectual imperatives: Patterns of interaction with external stakeholders

The CGS represents a mission-centred science council grappling to respond proactively in a shifting policy and reduced public funding environment, to balance its commercial and statutory mandates, and to build its reputation in South Africa as strongly as it has on the African continent.

We may thus expect that it will have three main types of partners: first, other knowledge institutions with which it collaborates on the statutory mandate. Second, clients of its commercial services – local and African governments, foreign funding agencies and donors such as the World Bank, major mining companies and junior mining houses, and the general public that use their mapping and analytical services. Third, local government and communities with which it engages in the course of the new geo-hazard and povery alleviation mandate. This section draws on the survey of scientists to map the patterns of interaction found amongst CGS scientists, in 2013.

A small group does not perceive interaction as an organizational priority

The total population of scientists was 157. The survey realised a high response rate of 75%, yielding a sample of 117 scientists. Of the sample, only a small group, 11% reported that they do not interact with external partners. There were no distinguishing demographic or positional attributes characterizing this group, except that they tended to have lower level qualifications: more than 50% of these scientists had an honours degree as their highest qualification, in contrast to 35% in the total sample.

The Weighted Average Index (WAI) of the main reasons provided by the 11% of scientists who do not interact is reflected in Table 6.2. The most frequent reason was that CGS units do not promote engagement, followed by those who reported engagement was not appropriate to the nature of their scientific fields. A lack of clear institutional policies on engagement and related items were ranked amongst the main reasons. Interaction is thus not perceived to be an organizational priority for this group.

Table 6.2: WAI of reasons for not interacting

Challenges		Not Engaged Frequencies				Wtotal	WAI
		1	2	3	4		
4	My unit or centre does not promote engagement	2	4	3	8	51	3.00
1	Engagement is not appropriate given the nature of my scientific field or discipline	4	1	5	7	49	2.88
9	Lack of clear institutional policy on engagement	2	6	4	5	46	2.71
13	Lack of partners' knowledge about research activities and priorities in science councils	3	4	5	5	46	2.71
2	Engagement is not central to my scientific role	2	7	4	4	44	2.59
5	Lack of clarity on the concept of community engagement or social responsiveness in my institution	5	2	5	5	44	2.59
6	Institutional recognition systems do not reward engagement activities sufficiently	6	2	3	6	43	2.53

Most frequent external Partners

CGS scientists report a wide range of external partners but the most frequent are knowledge partners, government and potential public beneficiaries. Table 6.3 shows the top five most frequent partners ranked using the WAI. South African universities are the most frequent external partner, with 86 scientists reporting engagement on a moderate to a wide scale. The nature of such interaction could be traditional academic collaboration, as reflected by a senior manager:

> … So we partner with the universities sometimes. So that my researchers, scientists, they have a partnership collaboration with universities, sometimes we partner with Stellenbosch, maybe UCT depending on the need…Yeah, our scientists are being actually trained by academics sometimes. They do, further their studies, PhD, but we form projects for their studies which is being done by an academic outside. So that's a collaboration between a university and also the council. Two of my scientists are doing MSC, one is doing PhD, that is through the University of Johannesburg, one is University of Pretoria. So they interact (Interview with senior manager 4, 2013).

Other African governments are key clients, so we need to interpret the item 'national government departments' with care. It could refer to SA government departments as was the intent of the survey design, but at CGS, it could refer to other national departments in African countries.

The strategic plan up to 2012 prioritised Africa development, and this represents a large proportion of funding. Hence, African governments and geological surveys are key external partners (Interview with senior manager 5, 2013).

Most of these interactions with external partners are project oriented as will be seen in the sections to follow. Individuals and households are also frequent partners, and this likely refers to the users of the museum and library services.

Table 6.3: WAI'S of external partners

Social partners		Engaged					
		Frequencies				WTotal	WAI
		1	2	3	4		
24	South African universities	7	7	44	42	321	3.21
26	South African science councils	10	21	44	25	284	2.84
3	National government departments	25	26	22	27	251	2.51
7	Individuals and households	25	27	30	18	241	2.41
1	Local government agencies	22	38	25	15	233	2.33

Multiple partners and networks?

One question is whether these partnerships with universities are traditional academic collaborations around geological surveys in support of the statutory mandate, or whether they involve universities as one of multiple partners in a strategic or applied network, addressing the needs of clients of commercial services, or aimed to address national social and environmental problems.

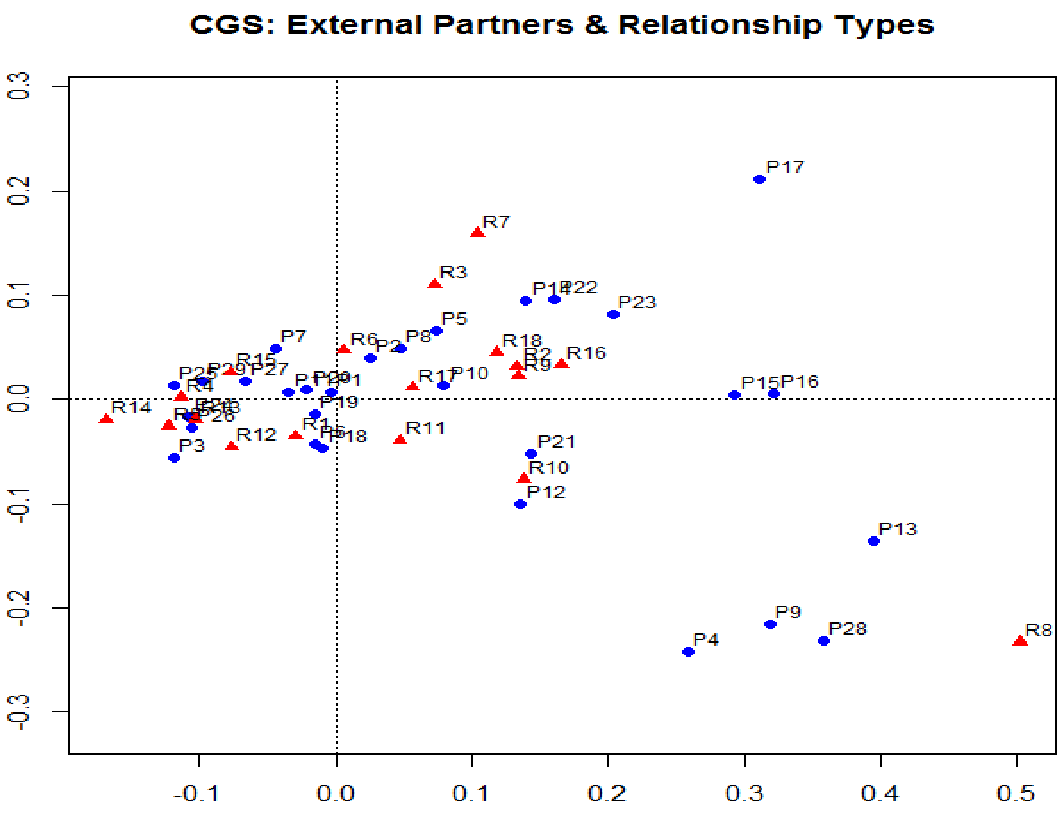
The degree of networking with multiple partners appears significant. The average number of partners was 10, and only 2 of the scientists reported a single partner. The highest number of partners reported went up to 22 partners, with 2 scientists reporting interacting with these partners on a moderate to a wide scale. A review of the best case examples provided by the scientists shows how the scientists might be involved in projects that have more than one stakeholder, in the form of a consortium or knowledge network. For example, researchers in the engineering geology unit, which deals with geohazards, reported collaboration with DMR, Department of Human Settlements, private companies, MQA students, individuals and local communities. The research contributed to an investigation of the causes of engineering structural failure in RDP houses, to, be used by the department and the other companies involved, to inform building improvements. Further examples are the involvement of international universities to bring expertise to networks, such as a project for

ESKOM to investigate seismic hazards, in collaboration with British and American universities; or the inclusion of university academics in a consultancy project, such as an investigation of rock falls for the Mine Health Safety Council and DMR; or partnerships with local universities to conduct national geological surveys in their country. There are also examples reported of more traditional collaborations with local and international universities, around post-graduate theses, sometimes attached to these larger projects.

The nature of relationships with external partners: analysis in terms of the CGS mandate

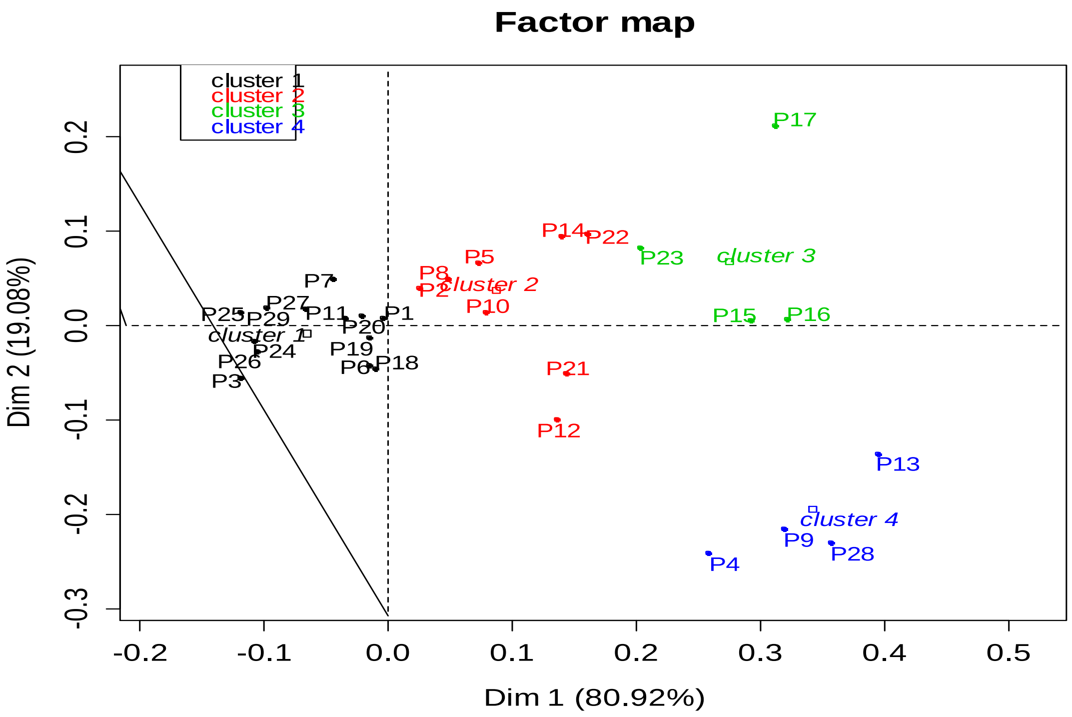
Hence, we need to examine the nature of the types of relationship with diverse external partners that predominate at CGS, as well as those that may be related to niche areas or emergent strengths. Figure 6.2 reflects a correspondence analysis map of partners in association with types of relationship. Dimension1 (x-axis) explains the greatest amount of variability and is more significant for the interpretation of associations. For this particular factor map, dimension 1 explains 80.92% while dimension 2 (y-axis) explains 19.82 % of the variance. The blue circles represent partners, and the red triangles represent types of relationship. So for example, the map reflects a strong association between the points P3 and R5/R12, which are located close to each other along dimension 1: national government departments as partners are more likely to be engaged through customised training and short courses and/ or research consultancy types of relationship. CGS scientists are more likely to collaborate with international science councils **(**P27**)** as partners on collaborative R&D projects (R15) and for research consultancy (R12). There is a close association between large SA firms **(**P18) and of SMMEs (P19) with the education of post graduate students (R1). Firms may be involved in developing future skills by funding post-graduate bursaries or internships of students who work at CGS and their partner universities. Or CGS may promote dissertations in fields that address the problems of large firms and SMMEs, and require their close involvement.

Figure 6.2: Correspondence analysis partners and relationships



To reduce complexity – for example, from 29 partners to a more manageable set - we conducted a cluster analysis, first, by the types of partners. Figure 6.3 reflects a factor map of four clusters of partners, each of which are associated with a similar set of types of relationship. The clusters close to the point of origin show the average, most typical sets of partners of CGS scientists, while those further away from the origin may reflect more atypical partners or activity on a smaller scale.

Figure 6. 3: clusters of partners of CGS scientists



Cluster 1, located along Dimension 1 in the left hand quadrants, groups the partners with whom CGS scientists most typically interact on a day to day basis. It is evident that these are the main government clients and knowledge partners, but also, firms and individuals that use CGS services, related to the traditional fixed and varied mandates: individuals and households, national government departments, local government agencies, development agencies, multinational companies, large SA firms, national regulatory and advisory services**,** international science councils, SA science councils international universities, SA universities (P7, P27, P24, P25, P29, P26 P3,P11, P1, P20, P6, P18). Interaction with these partners is likely to be driven by financial imperatives and the policy mandate to contribute to economic development. This is corroborated in a recent CGS stakeholder management plan, which distinguishes key stakeholders (defined in terms of the knowledge base and financial support) and targeted stakeholders (defined in terms of offering a niche market to generate business) (CGS 2014). The lists of each group include instances of the partners in Cluster 1.

In contrast, Cluster 2, along dimension 1 in the upper right hand quadrant, consists of a set of public and social partners, related to the newer mandate to enhance the quality of life and environmental sustainability: schools, community organizations, NGOs, specific local communities, provincial governments, trade unions, commercial farmers and small scale farmers (P5, P14, P10, P8, P2, P22, P21, P12). Interaction with these partners is likely to be funded by government or donors, and relates to the socially responsive imperatives added to the CGS mandate after 2009.

In cluster 3 and 4, we find atypical partners with whom a minority of scientists might interact. Cluster 3 in the upper right hand quadrant consists of religious, sectoral and political organisations and social movements (P17, P23, P16, P15). Cluster 4 in the lower right hand quadrant consists of civic associations, welfare agencies, hospitals, clinics and health centers (P13, P9, P28, and P4). These will require careful analysis, to determine the nature of interaction.

The analysis below will focus on the two main clusters 1 and 2, those most common and most directly related to the core knowledge work of CGS, but will need to establish what the kinds of interaction with partners in clusters 3 and 4 entail.

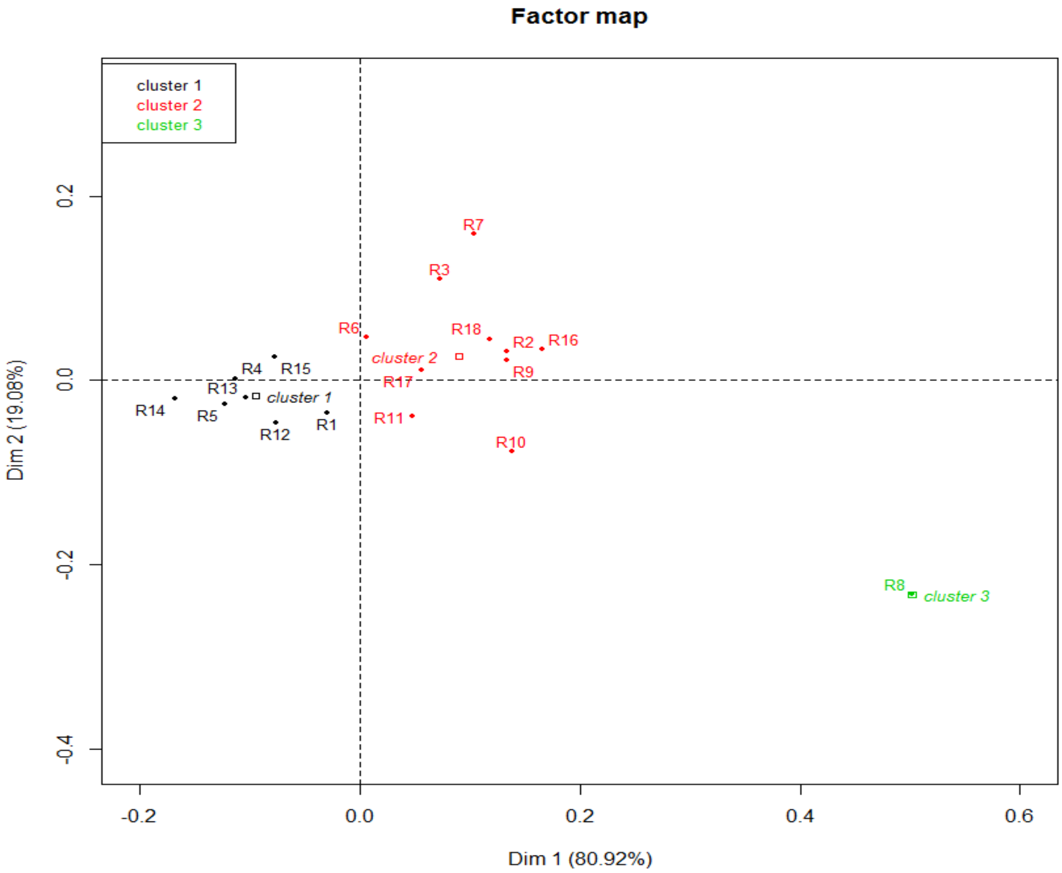
Two distinct clusters of types of relationship

Specific clusters of partners are associated with distinct types of relationship. The most frequent types of relationship, as may be expected based on the management interviews, are research consultancy and collaborative R&D projects (Table 6.4 below). These are followed in rank order of WAI by education of post-graduates, other professional development relationships and contract research.

Table 6.4: WAIs of types of relationships

Relationships		**Engaged**						
		Frequencies					WTotal	WAI
		<>	1	2	3	4		
12	Research consultancy	100	10	19	39	32	293	2.93
15	Collaborative R&D projects	100	15	21	29	35	284	2.84
1	Education of post-graduate students so that they are socially responsive	100	26	27	20	27	248	2.48
4	Continuing education or professional development	100	23	29	28	20	245	2.45
14	Contract research	100	36	13	22	29	244	2.44

Figure 6. 4: Cluster analysis for type of relationships



If we cluster the data by types of relationships as in Figure 6.4, two distinct clusters emerge.

Cluster 1 in the left hand quadrants is associated with the core knowledge generation and dissemination activities: continuing education and professional development, collaborative R&D projects, technology transfer, contract research, customized training and short courses, education of post graduates and research consultancy (R4,R15,R13,R14,R5,R1, and R12). This cluster of relationships is associated with the traditional partners, Cluster 1 in Figure 6.2

The focus is research consultancy/ contracts and services for clients that may include collaboration with knowledge partners, particularly post-graduate students. A typical such contract was conducted for provincial departments of Disaster Management and of Roads, to compile an inventory of landslides and a susceptibility map, to be used for spatial planning and hazard mitigation programmes. Other contracts and consultancies reported were likely to involve assessments of seismic activity, or the presence of geo-hazards, geological surveys and mapping of specific terrains, assessment of the impact of mining, particularly acid mine drainage, and recycling of waste or decontamination.

There were few examples cited of technology transfer in the sense of CGS developing new technology that is diffused to external partners. Indeed, the relationship with international universities may involve technology transfer *to* CGS, primarily taking the form of sharing of expertise and capacity building for local scientists: continuing education and professional development (R4), as well as customized training and short courses (R5) and technology transfer (R13) (Figure 6.2 above).

Cluster 2 in the right hand quadrant relates to the expanded social development mandate of contributing to poverty alleviation and solutions to problems of energy, human settlements and urban planning. These types of relationship are more strongly associated with Cluster 2 partners: expert testimony, collaborative curriculum design, policy research analysis and advice, joint commercialization of new product, voluntary outreach programmes, community based research projects, design and testing of new product, monitoring evaluation and needs assessment, participatory research networks and design prototyping and testing of new product (R7, R3, R6, R18, R2, R16, R9, R11, R17, R10).

Examples reported are a number of networks between CGS, department of Water Affairs, local communities and NGOs or private companies, to develop and monitor ground water for community supply. They may include NGO activities in relation to livelihoods that rely on the water supply, such as vegetable planning. Such projects typically result in the drilling of new boreholes, particularly in areas in which there has been acid mine drainage contamination. The geological survey and repository of CGS is thus being used to the benefit of new kinds of external partners:

> …the farmers were reporting calves eating soil and so the veterinarians actually contacted us to hear whether we could give an explanation and luckily we had done the sampling in those areas and we could say but let's look on our maps, geochemical maps to see what's going on and so on; and it turns that the soils there were very iron deficient. So the calves were instinctively licking the soil or on metal fence posts to supplement their diet but they weren't getting any iron because the soils were very poor and also the grass that grows from those soils were very deficient in iron (Interview with senior manager 5, 2013).

In particular, the shift to include geohazards in the mandate of CGS has meant more direct interaction with communities and other social development partners:

> That is why every year we are given responsibilities of going out there, identifying the dangerous holes that are closer to communities and fill them. For example, the one that we worked in Giyani, last year, we could see that within the settlement, here is a rondavel and

> about 20 meters from the rondavel is a big hole, and people are living with a hole next to them, because of the old mine, because nobody did anything about that. And also for example, looking at the problem of asbestos, when we went to Northern Cape we found out that even the materials used to build some of the houses came from old asbestos dumps, and the school grounds where the children are playing, they are playing on that waste which is so dangerous (Interview with senior manager 6, 2013).

CGS scientists' role in networks relates to geological surveying, but it is evident that interaction with partners in this cluster requires new types of relationship, and new skills:

> We approached it from a typical scientist point of view but we have discovered we have to interact more with people. With disaster management, we try do outreach programmes to educate people on what to do… (Interview with senior manager 7, 2013).

Hence, we conclude, that there are two predominant clusters of interactive activity within CGS. The first is driven by financial imperatives and potentially contributing to global competitiveness, but intersecting in complex ways with its traditional knowledge imperatives, in terms of the fixed mandate as a geological survey. The second cluster is driven by a social responsiveness mandate to contribute to inclusive development. It draws on the repositories, surveys, and maps of CGS scientists, but requires different roles and new types of relationships.

Nature of interactive activity in and between each cluster

While these clusters identify the strongest trends by reducing the large number of variables, it is equally important to understand nuance and complexity. There are multiple possible combinations that include partners or types of relationship across the clusters. In this section, we draw on Figure 6. 4 above as well as the best case examples cited, to reflect on the nature of interactive activity in and between clusters, as well as insights into the smaller, atypical cluster 3 and 4 partners.

Inspection of Figure 6.2 above shows a close association between individuals and households (P7) and collaborative research and development projects (R15). One such network reported used remote sensing and satellite imagery to assess the impact of mining activities on the social and natural environment in a small rural municipality. Partners include small and large mining companies, local and national government, local business in the form of the chamber of business, Black Management Forum and so on, and NGOs in the form of churches, civic organisations, labour unions and environmental organisations. The focus was to generate indicators through a bottom up, participatory approach, linked to images generated by earth observation tools. These could address issues in relation to air and water pollution, informal settlements, land subsidence and so on. The project is ongoing and is exploring the relationship between urban change and mining activity by using modelling and scenario building programmes.

Such a network throws light on the activity with partners in cluster 3 (Figure 6.3 above). Religious, sectoral and even political organisations or social movements might play a key role in building relationships with local communities, and ensuring the sustainability of research and technology transfer initiatives, which they are better placed to do than the CGS scientists.

A similar complex remote sensing network involved a national regulatory agency, private companies and the ARC, to map an area where mining had closed down, using satellite imagery, with the aim of rehabilitation and decontamination. The firms conducted the engineering work, while the local community was employed to do the manual work, and the ARC collected field data. Here there were direct (although temporary) livelihood opportunities created, and some areas were rehabilitated and used for new settlements. However, there was also a common perception expressed, of indirect interaction with communities in a more generalized sense. So, understanding the geology of a region can inform the location of new mines or areas for livelihood development, which ultimately, can contribute to alleviate poverty of the local communities. This does not require the active involvement of CGS scientists with local communities in the same way.

Atypical associations may reflect emergent niche areas of expertise, as appears to be the case with Cluster 4 of partners (Figure 6.3 above): civic associations, welfare agencies, hospitals, clinics and health centers. Medical geology was reported as an emergent niche CGS, in partnership with the MRC, which had requested geochemical data to link contaminants and illness, leading to collaboration and growing a new area.

There was also evidence of atypical philanthropic, charitable relationships to communities through donations and collections, for example, to orphanages (Interview with senior manager 4, 2013). Reflecting this trend, there is a strong association between community organisations (P14) and voluntary outreach programmes (R2). This might be through scientists' private philanthropic endeavors. Related forms of 'organisational philanthropy' are evident in the form of school awareness programmes, organised to promote geology among learners, for example.

These very different types of interaction are likely to lead to distinct benefits and outcomes, which we examine in the next section.

What are the benefits and outcomes of interaction?

Relationship types and outputs

Table 6.5 below shows the most frequent outputs of interaction, reflecting the distinctive nature of CGS as a national facility with a fixed mandate. In contrast to some of the other science councils and all universities, the most frequently reported outputs are reports, policy documents and popular publications, as well as scientific collaborations. These relate to their applied mandate in terms of interaction with both the competitiveness oriented partners (cluster 1) and the community oriented partners (cluster 2). Academic outputs related to its knowledge generation role, such as publications and dissertations, are less frequently reported than at the other science councils.

Table 6. 5. WAIs of outputs

Outputs			**Engaged**					
		<>	1	2	3	4		
1	Reports, policy documents and popular publications		6	20	38	36	304	3.04
2	Scientific collaboration		11	18	36	35	295	2.95
3	Academic publications		16	26	21	37	279	2.79
4	Post-graduates with relevant skills and values		20	25	33	22	257	2.57
5	Dissertations		29	17	31	23	248	2.48

Table 6.6 below summarises the significant associations observed from a correspondence analysis conducted to determine the type of relationship likely to yield a specific output. Academic publications are most likely to result from collaborative R&D projects and contract research – and we have seen the key role played by knowledge partners alongside firms and government in networks.

More significantly, scientific discoveries were reported as most likely to emerge from community based research projects. This suggests that CGS scientists are learning significantly and developing new knowledge through their interaction with individuals and households in local communities, and other related partners. Similarly, relationships around the education of post-graduate students are likely to promote scientific collaboration, suggesting that this form of interaction is of value to CGS scientists.

Table 6. 6. Summary of association between relationship types and outputs

Relationship type	Outputs
R15 collaborative R&D projects. R14 contract research	O4 Reports, policy documents and popular publications O2 Academic publications
R1 education of post graduate students so that they are socially responsive	O6 Scientific collaboration
R16 community based research projects	O11 scientific discoveries
R11 monitoring, evaluation and needs assessments	O1 post graduates with relevant skills and values

Benefits from types of relationship: strategic insights

What are the wider benefits of interaction in these clusters for CGS and for its partners? Table 6.7 reflects the most frequent outcomes and benefits to CGS scientists, through their relationships with the different external partners. What stands out first is that interaction is not perceived to yield benefits very frequently for the CGS scientists - the highest ranked outcome yielded a relatively low WAI score of 2.8.

Second, the WAI ranking confirms that external interaction is of major reputational benefit to CGS's core knowledge role, for some scientists at least. Reputation is ranked as the greatest benefit, although notably, only on a wide scale to a small group of scientists (22 rated the item 4). This is followed by relevant research focus and new research projects, and by theoretical and methodological development in the scientific field, all of which relate to their knowledge role. Training and skills development, and public awareness and advocacy are potentially mutually beneficial, to both CGS and its external partners.

Table 6. 7: WAIs of outcomes and benefits

Benefits		Engaged					
		Frequencies				WTotal	WAI
		1	2	3	4		
17	Scientific and institutional reputation	9	23	45	22	278	2.81
16	Relevant research focus and new research projects	12	28	36	23	268	2.71
18	Theoretical and methodological development in a scientific field	17	21	37	24	266	2.69
6	Training and skills development	14	28	33	24	265	2.68
1	Public awareness and advocacy	22	31	31	15	237	2.39

Third, it is evident that each cluster of partners and types of relationship is likely to yield distinct benefits. Table 6.8 below provides an overview by summarising the correspondence analysis of the association between types of relationship and their likely outcomes and benefits, with the correspondence map reflected first in Figure 6.5.

Figure 6. 5: Association between relationship types and outcomes and benefits

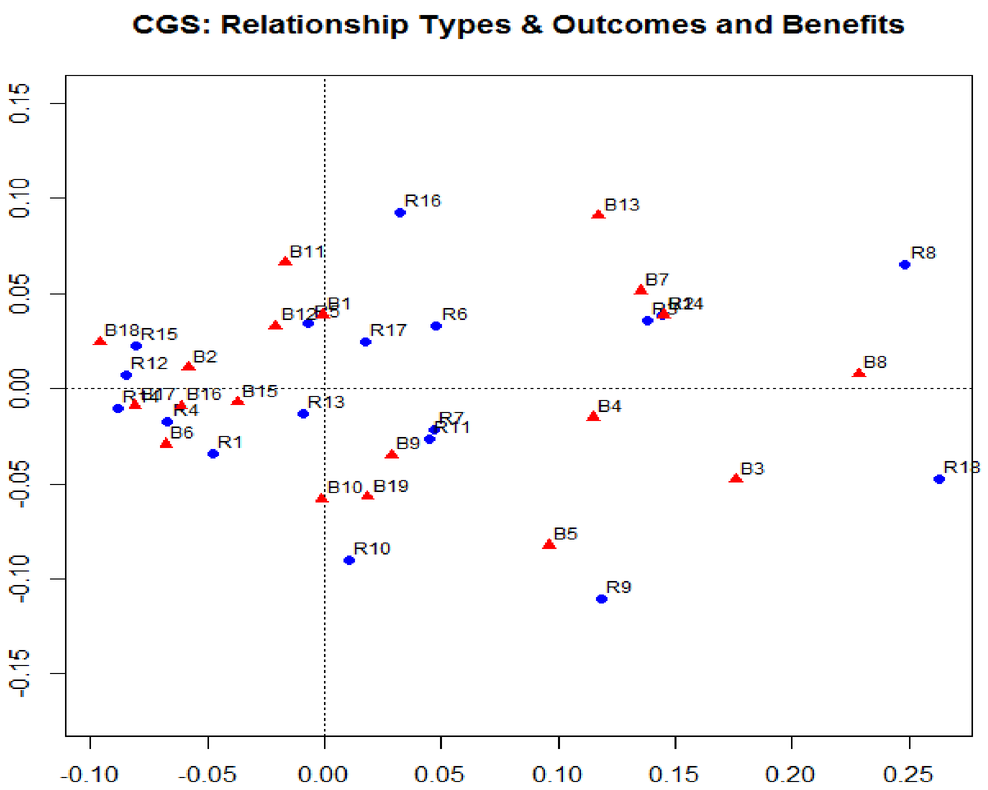


Table 6. 8: Summary of association between relationship types and outcomes and benefits

Relationship type	Outcomes and benefits
R14 -contract research R4- continuing education and professional development	B17 Scientific and institutional reputation B16 Relevant research focus and new research projects B6 training and skills development
R15 - collaborative R&D projects R12 research consultancy	B18 theoretical and methodological development in science fields
R1- education of post graduate students so that they are socially responsive	B6 training and skills development
R5- customised training and short courses	B1 public awareness and advocacy B12 regional development
R2 voluntary outreach programmes R3 collaborative curriculum design	B14 incorporation of indigenous knowledge B7 community employment generation

Fourth, there is strategic question we can raise - whether the pattern of type of relationships yields the kinds of outcomes and benefits that CGS has prioritized in its organizational mission and strategies. For this purpose, we use the statistical technique of classification trees, which can show differentiation between groups of scientists, to analyse the association between the outcomes and types of relationships in a more fine-grained manner. Essentially, the technique assigns each scientist to a group based on their *most frequent outcome*.

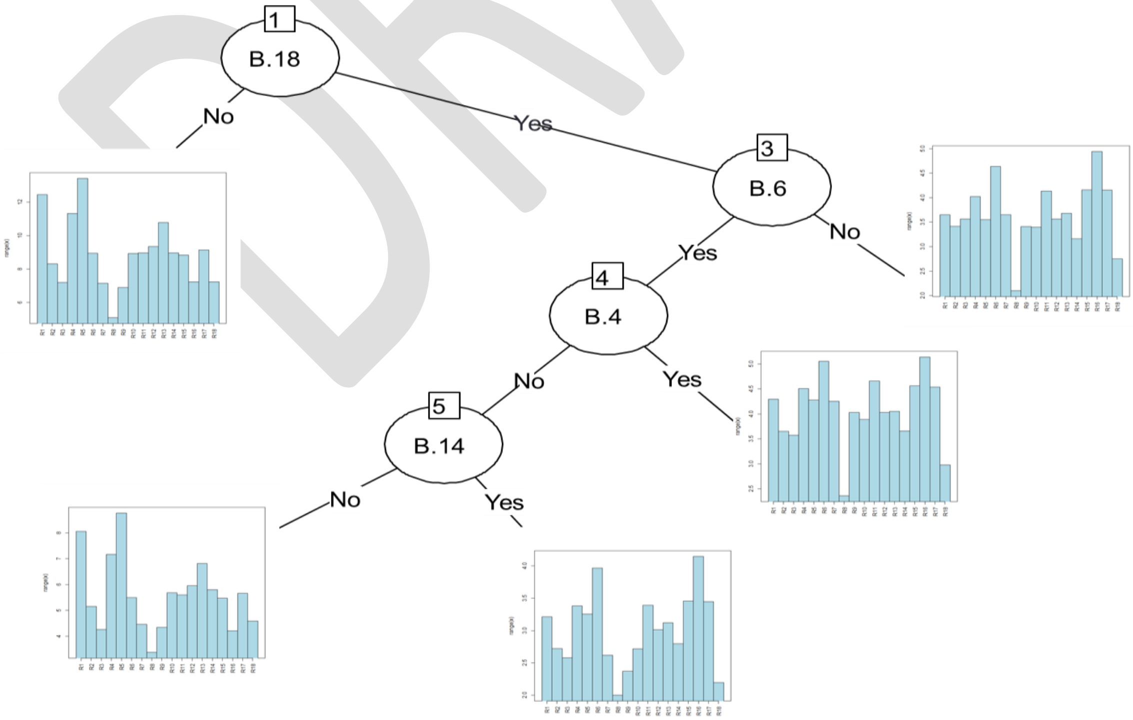
Figure 6.6 shows the resulting tree for an analysis of outcomes and benefits, with four 'splits' that differentiate distinct patterns of interactive activities. Each graph reflects the type of relationships most strongly associated with that group of individuals. A glance shows that the configuration and scale of each graph differs considerably.

The first split is by the outcome of 'theoretical and methodological development in scientific field' (B18). Such an outcome is critical to the mandate for scientific excellence, and the fixed mandate of CGS as a geological survey. We can analyse those who do not report this outcome and establish the types of relationship they are most likely to participate in. And so on, through the second split, training and skills development (B6) to the third and fourth splits, policy interventions (B4) and incorporation of indigenous knowledge (B14). Here we discuss a few examples, to show how the analysis can be used to raise strategic questions for a science council.

Inspection shows that the group of scientists who *do not* report scientific contributions as a benefit (No to B18) are interacting predominantly through teaching and training types of relationship: education of post graduates, customized training and short courses, and continuing education and professional development, as well as technology transfer. This is important to disseminate CGS research and expertise, and to build future capacity. It is a means of achieving the CS strategic goal of 'rendering of geoscience knowledge services, advise and products'. However, if too many scientists are involved in training type relationships primarily and are not interacting in ways that benefit scientific reputation, this could have a negative impact on achieving the core scientific mandate.

In contrast is the group represented in the graph on the bottom left hand side. Their interaction *has had the benefit* of both scientific reputation (B16) and training (B6), but not policy interventions (B4) or incorporation of indigenous knowledge (B14). The most common types of relationship of this group are also customized training, post-graduate studies, continuing education and technology transfer. However, this group is reporting benefit to scientific reputation. This group represents the scientists who are more likely to address the core CGS mandate, interacting with cluster 1 partners through cluster 1 types of relationship - the strongest trend within the CSIR. The strategic question is whether their interactions lead to a wide enough spread of benefits, as intended in CGS goals and mandate.

Figure 6. 6: Spliting on outcomes and benefits



The group that *does* report scientific reputation building benefits is further split by those who reported the outcome of training and skills development (B6) as important, and those who do not. The latter group differs significantly from the previous two (No to B6, the graph on the upper right hand side). Their interaction has had scientific benefit, but not training and skills development benefits. The types of relationship of this group are linked to the social responsiveness mandate: community-based research projects, policy advise, collaborative R&D, participatory research networks and M&E. There is a similar group that combines scientific reputation, training and policy interventions (yes to B18, yes to B6, yes to B4, graph second from the top on right hand side). This group was most likely involved in community based research projects, policy advice and M&E types of relationship. If CGS wishes to promote activity in relation to the social development mandate, the analysis has identified a niche of collaborative activity that can be deepened, and a group of scientists with whom to work.

Conclusion

The chapter began by arguing that CGS grapples to balance its core role as a geological survey with new demands to implement a commercialization strategy, contribute to knowledge generation and production of a new generation of scientists, and conduct research to address government social developmental priorities - in a financially constrained environment.

The analysis has shown how these dynamics shape its interaction with external partners. There are two distinct clusters of interaction. The strongest trend is aligned with the traditional mandate as a geological survey. Interaction is with a cluster of African and national government, firm and knowledge partners, and typically takes the form of research consultancy, contracts and collaboration, as well as in relation to post-graduate education, training and skills development. The outputs are most likely to be reports and scientific collaboration, and to a lesser extent, academic outputs. The outcomes of interaction are primarily to enhance scientific reputation, but there are groups of scientists that focus primarily on training rather than scientific reputation, for whom the contribution to knowledge generation is clearly not as significant.

This pattern of interaction addresses CGS's roles as a geological survey and the production of a new generation of scientists. Technology transfer and commercialization activities are not a major emphasis for scientist – particularly given the pre-and post-competitive stages of the value chain in which CGS operates.

A second cluster of interaction, on a much smaller scale, responds to government social development imperatives. Interaction is with communities, NGOs, and other civil society actors, in various forms of policy, monitoring, collaborative and participatory research relationships. CGS expertise in mapping and surveying is extended to address a wide range of geohazards. Significantly, this pattern of interaction is perceived to yield benefit to scientific reputation for groups of scientists, and can inform policy interventions and the incorporation of indigenous knowledge.

The organization is displaying a more strategic approach to coordinate and align its activities internally to support and promote interaction with key clients and stakeholders. These have the potential to address some of the organizational gaps and blockages identified at the time of research.

CHAPTER 8: A mission oriented public research institute facing the challenge of revitalisation: The Medical Research Council

Introduction

At the time of empirical research in 2012, the Medical Research Council (MRC)[9] was developing a "revitalisation" strategy and undergoing a major process of strategic re-orientation and reorganisation. Conducting research in an organisation in flux, in which researchers are insecure about their futures, as will become evident, impacted on the data gathered. Moreover, the conditions, trends and patterns described in the analysis will have changed significantly in the present. The MRC has undergone major changes since 2014, in terms of leadership, strategic focus and organisational structures (MRC 2014). All of the research evidence presented in this chapter needs to be viewed in the light of this organisational shift.

The MRC is a mission-oriented centre reporting to the Department of Health. Its primary roles relate to 'research, development and technology transfer to promote the improvement of the health and quality of life of the population', which it does through both research performing and funding modalities. The balance of goals driving its activities is thus likely to fall more strongly on the contribution of its research and innovation to the quality of life and inclusive development, as well as scientific excellence and connecting to global knowledge systems. These goals would shape a distinctive pattern of interaction, particularly in terms of the nature of external partners.

Established in 1969, the organisation has evolved in a complex decentralised manner, with offices housing research performing institutes, called 'intramural' units, in Cape Town, Pretoria and Durban. In addition, the organisation funds 'extramural' research units and projects located within university departments, including research programmes led by internationally recognised scientists that function as centres of excellence. While the MRC was regarded as a national asset in the 1997 SETI review, by the time of a SETI Review in 2010, it was an organisation in turbulence. Analysis of strategic documents suggest a science council struggling to adapt to the multiple demands of shifting national health research priorities and paradigms, of scientific excellence, of declining funding and of its role as driver and coordinator of health research in the national system of innovation. It appears that the organisational structures, mechanisms and capabilities had not changed sufficiently to support new goals, although there remained pockets of excellence, and the research had significant impact on health over time. This set of conditions means that interaction is driven primarily in an ad hoc manner, by individuals, whether heads of units, scientists or managers.

[9] The MRC is a statutory council in terms of South African Medical Research Council Act 19 of 1969 and 58 of 1991.

In this chapter, we first set out the history of the MRC, before considering the balance of goals underpinning its mandate, and the absence of structures and mechanisms to promote interaction, in an organisation undergoing a process of change. In the second part of the chapter, we consider how the interactive activities of scientists reflect the ways in which they have mediated national and organisational mandates.

Medical research to deal with local problems: a brief history of the MRC

Medical research in South Africa can be traced back to attempts to deal with local diseases in the colonial period, as the frontier spread eastward and northward driven by the cattle-farming economy. Key moments reported in the MRC's version of its role in medical research history are 1864, with Dr John Harley's discovery of bilharzia ova on the Eastern Cape frontier, followed by Sir David Bruce's demonstration in 1895 of the nagana cycle, a cattle disease spread by a species of tsetse fly (MRC 1999).

The first formal research organisation emerged in response to the health needs of the mining sector. In 1912, the South African Institute for Medical Research (SAIMR) was established as a joint venture between the Union government and the Chamber of Mines. Much of its work focused on routine screening and diagnostic work, driven by the high incidence of new illnesses among Black mine workers. Scientific breakthroughs dealing with local health challenges were recorded, such as the identification of two malaria transmitting anopheles mosquito species.

Chapter four described the formation of the CSIR in the period after 1945, when research and development intensified globally, and the establishment of a legislative framework for overall government control and public funding of scientific research in South Africa. The formation of the Medical Research Council was interwoven with diversification of the roles of the CSIR in the 1960s. Although the mandate of CSIR was a broad one, it did not include medicine as a formal mandate. Nevertheless, the CSIR was responsible for coordinating the direction of medical research and funding research units in university medical schools, through its Committee for Research in Medical Sciences (CRMS). In 1967, the success of the first human heart transplant in the world connected local medical research to international science, and served as an impetus to grow medical research in the country. Through the CRMS, the CSIR sponsored and established research units within medical schools, and was instrumental in the formation of the MRC in 1969. A large cohort of the first researchers at the MRC came from the CSIR. Initially, the headquarters of the new mission-centred group were based at CSIR, but as an autonomous body, the MRC had no formal connection, and submitted its Annual Report to Parliament. The initial research focus was on "causation, progression and reversal of common diseases" in line with the predominant medical paradigm at the time.

Given that the first president of the MRC was the Dean of the Faculty of Medicine at Stellenbosch University, in 1971, the MRC headquarters were moved to Cape Town, in close proximity to two teaching hospitals. The principle was that the MRC should primarily direct and fund research units built around excellent scientific leaders, based in existing university medical schools, as well as research groups based in hospitals, along the CSIR model – the origins of the extra-mural programmes. Increasingly, however research institutes were set up, staffed and operated within the MRC itself – the origins of the intramural programmes. The focus of institutes was in response to local health problems: nutritional diseases, environmental diseases, diseases in a tropical environment, medical biophysics, TB, biostatistics and biomedical communication. The intent was that research units, groups and institutes were to be funded for limited periods and reviewed regularly in line with changing health priorities.

During the 1980s, with the growing emphasis on income generation that was to culminate in the Framework Autonomy policy of the apartheid government, a subsidiary company was established to channel commercialisation of MRC produced technology. By the time the first president retired in 1988, the MRC was feeling the pressure of international isolation caused by academic sanctions against the apartheid system, and the growing pressure for change in South Africa, and indeed, the imperative to consider 'the health needs of Southern Africa' (MRC 1999). This period of organisational change provided an opportunity for the MRC leadership to review the path it had taken since 1969. The 1989 Annual Report called for reflection on the ways in which research was prioritised, funded and organised, in terms of its appropriateness for shifting local conditions. The result was a new MRC Act (1991), the establishment of an independent scientific board to determine research policy and a new leadership and accountability structure. This change was a manifestation of the diversification and shift in science councils' roles from 1989, in response to global and national political and economic dynamics, as discussed in chapter 2.

In 1992, the period of political transition, further strategic changes were instituted, shaped by the new national science policy of 'Framework Autonomy': rationalisation and reprioritisation of research programmes and services, an emphasis on efficiency and on the commercialisation possibilities of the MRC company[10]. State funding was in decline, and the organisation increasingly turned to partnerships with commercial firms to sustain its existence. At the same time, political shifts were driving a new more inclusive and equitable vision. MRC documents articulated the need to refocus, and to shift orientation away from curiosity-driven research towards applied and 'problem-solving' research, more strongly needs-driven. The focus shifted to prioritise the significant health problems of the majority of the population. The Department of Health had adopted a new

[10] However, in 1993 the commercial wing, was dissolved as unviable and was liquidated at a cost to the council.

approach, to define "Essential National Health Research" priorities, which included a focus on the social conditions impacting on good/ill health, and on the health systems delivering interventions. The MRC was challenged to redefine its programme and internal structures in response. These changes included the need for increased communication with scientists and other organisations outside the country. Affirmative action was implemented as an employment policy, bringing about internal institutional changes.

Change and diversification of roles at MRC after 1994: evidence from SETI reviews

This section draws on the SETI Reviews of the MRC for the periods 1997 to 2010, to analyse the strategic mandate and functions of the MRC relative to shifting national policy, economic and social conditions and scientific dynamics. The 2001 Review was external, used by the MRC to inform its strategic planning process, and the MRC prepared a reflection to DST for a SETI review in 2006 (MRC 2006) which did not take place. An independent external review was conducted in 2010 (MRC 2010).

A positive basis for addressing new national health priorities: 1997 SETI Review

The 1997 SETI review of the MRC by an international panel was positive, in terms of its evaluation of the transformation of the roles, function, and organisation and funding of the MRC using the new criteria for science councils, as well as its alignment with the new national health priorities and approach:

> Of all of the SETIs covered in this review, it has the closest operational linkages to the priorities and programmes of the Ministry to which it is attached (DACST 1998).

The MRC was reported as successfully inserted in international scientific networks, in that it had attracted private and public foreign funding. The Chairman's report of 1998 likewise claimed that the MRC had become a fully-fledged client-based SETI, in that it had forged a number of international partnerships and collaborations resulting in significant contract funding which saw the organisation reaching a healthy financial status. The conclusion was that the MRC was a "national asset".

The main concerns of the SETI review related first, to the MRC retaining its dual research performing and agency funding roles. Nationally, all agency funding of research in higher education and science councils was in the process of being centralised, with the formation of the National Research Foundation, leaving science councils with their research performing functions only. The MRC was reported to resist a formal separation of these functions, and determined to retain them. Concerns were raised about the potential for conflict of interest, and for lack of coordination of funding for health research, and recommendations were made for transparency in allocation of funds to avoid such. Second, the concern was to integrate a more comprehensive social scientific approach into the work of the MRC, given the complexity of health problems of the majority of poor and excluded South Africans, that required more than medical interventions to be addressed.

"Building a healthy nation through research": 2006 internal review

Over the next decade, and based on the recommendations of the 1997 SETI review in general, three core functions were defined, to achieve the goals: facilitating national health research (through extra-mural programmes), capacity development, research performance and technology transfer (through intra-mural programmes) (MRC 2006). The MRC decided on research priorities in response to three policy imperatives: specifically, the 'burden of disease and health profile' of SA, as determined by structures of the Department of Health; more generally, the strategic priorities for health and development as set out in national government policies; and the need for capacity building in health research. These commitments were summed up in the vision of "building a healthy nation through research".

One concern for MRC in that period was the need to increase the public funding allocation. Leadership argued that 1% of the health budget should be allocated for research in line with international practice, and that the MRC should control this national budget. From 1998, the MRC's budget allocation from government was almost doubled, but the organisation claimed this represented only 0.3% of the health budget, and 18% of government health research funding (MRC 2006). Accordingly, the MRC increasingly diversified its funding sources, with a growing income from local and foreign contracts, which was perceived to increase the risk that research priorities would be donor driven, and increase the percentage of contract researchers. For our purposes, what is significant is the extent to which financial imperatives began to drive contract forms of interaction with external partners, but based on scientific excellence, rather than commercialisation goals. The MRC reported that it did not pursue contract income from the private pharmaceutical sector. Most of the contracts were based on competitive grant processes from public foundations in the US and UK (NIH, Gates Foundation, Wellcome Trust and the like), which was testament to the quality and reputation of MRC research, and the apparent responsiveness to pressing national and global health issues. Thus, global research and innovation partnerships and networks were forged, in response to major health challenges such as HIV/AIDS and TB drug development. Relationships with the DoH were strengthened, as well as with provincial health departments.

The balance of funding between research performance and research funding roles was an ongoing concern, however. The 1997 SETI review had recommended that the MRC shift funds from intramural to extramural programmes, and consolidate intramural research into larger, more effective programmes shaped by national health priorities. In 2006, the MRC reported that it had shifted the ratio of baseline funding for direct research costs from a ratio of 45:55 in 1997 to a ratio of 24:76 by 2005[11], as extramural research was more effective in leveraging funding. These figures, however, did not include the high costs of maintaining the intramural staff complement and the extensive organisational support system and infrastructure. A further complication in interpreting this claim is that the boundary between intramural and extramural research was not impermeable. For example, the MRC hosted the SA AIDS Vaccine Initiative, which in 2006 was funded by Eskom, DST and DoH, with 15 units based both within the MRC and university medical schools, employing 220 people. This programme had filed 5 patents.

Such activities gave impetus to the strengthening of the organisational structures for managing intellectual property and technology transfer. The MRC reported that it hosted public facilities, technology platforms and research support services such as a primate research facility, bioinformatics supercomputer, online knowledge portals, training courses in biostatistics, and a radio production studio to promote community health issues. These all represent channels for interaction with external stakeholders - students and scientists in universities, communities, government agencies and policy makers – and commitment to the public science mandate.

The need for revitalisation and refocusing: 2010 SETI Review

The 2010 independent SETI review was conducted at a time of organisational turbulence and change, driven by the need to appoint a new board and leadership, undertake legislative amendments and develop a new strategic direction. The reviewers found that whereas past reviews had urged the expansion of the extramural programme to deepen resources, the opposite had occurred, so that the costs of supporting the MRC's intramural programmes and infrastructure had expanded at the expense of research funded in extramural units:

> …it largely dominates the organisational model and budget, because of its extensive infrastructural, financial, human resource and other operational needs, and its dependence on external grants acquired from both within and outside the country, all coming with stringent regulatory and reporting requirements. As a result, most of the substantive enabling support previously provided to extramural units in the form of formal posts and equipment has been progressively diluted down to "seed" funding for operational costs, short-term assistantships and minor equipment (DST 2010: 4).

The reviewers noted a lack of cohesion within the MRC at that point, with dissension between the board, the executive, and leaders of internal and external units, which was leading to low morale, thus limiting its potential contribution. Hence, the panel called for greater public investment in a "refocused" and "newly energised" MRC and provided a number of recommendations to address

[11] This ratio excluded the costs of intramural salaries, operating costs, capital development and so on

particular blockages and gaps. These related to changing the mandate, governance and operation of the MRC, to deepen its contribution to the shifting national paradigm of “Research for Health”, through a renewed focus of core business on innovation, translation and research impact. The key recommendations highlight the challenges faced by the MRC:

- A shift to report directly under DST, given the complexity of health research, the perception of limited capacity within DoH to guide the MRC’s direction, and the number of other agencies funding and conducting health related research (such as NRF, HSRC and CSIR).
- Better structures to coordinate national Research for Health initiatives throughout the national system of innovation
- Interventions to address governance difficulties and tensions between the Board and the Executive management (prevalent at that time), to ensure that the standards set out for SETIs are followed
- Reorganisation of internal operational, support and reporting structures to define roles, improve efficiency and facilitate an organisational “turn-around strategy”
- Renewal and restructuring of units to reduce duplication and obsolence, using transparent criteria in a systematic and rigorous manner
- A shift to more cost-effective allocation to high-quality extramural activities, alongside a higher level of baseline funding
- *Efforts to improve linkages with other science councils, and synergies between intra-and extra-mural programmes*
- Revision of the approach to performance management to address strategic planning priorities
- Revitalisation of clinical research, in the face of a drastic decline of funding, which had driven scientists in university teaching hospitals to fund research through drug trials contracted by pharmaceutical companies, which is not in the interests of the national goal of Research for Health.

Implementation of these recommendations, the SETI Review proposed, would drive and depend on closer interaction, collaboration and partnerships with external partners in the universities, science councils, national and provincial governments and other actors in the national system of innovation.

A period of uncertainty

It seems that following the 2010 SETI Review, a period of uncertainty ensued, characterized by a lack of firm direction and changing leadership. A new Board was appointed for three years from

November 2010, and prepared a new Strategic Plan for 2011-2013, which was rejected by the Department of Health. Subsequently, a revised strategic plan was accepted for the period 2012/2013 – 2016/2017.

A new vision was articulated, “building a healthy nation through research and innovation” with a new emphasis on conducting and funding “relevant and responsive health research, development and research translation” (MRC Strategic Plan, 2012). The new strategic plan proposed a “research translation mechanism” that would “serve as a clearing house for tested interventions that are ready to be implemented by the department” (MRC 2012: 11), as well as a new strategy to promote community engagement in terms of the significance and potential contribution of MRC research. Strategic goals and targets were identified that would potentially drive greater interaction, in terms of promoting health through research, through innovation and technology development, through improved organizational performance and through collaboration with partners at all levels from global to local, to improve health outcomes.

A new leadership and strategic direction

This strategic plan, under the leadership of an acting president, was tabled in March 2012, but in July 2012, a newly appointed president set out his own vision and turn-around plan for revitalizing the MRC, based on a thorough process of consultation. This revitalization strategy confirmed a number of the challenges identified by the 2010 SETI Review as the starting point for intervention:

1. It was recognized that pockets of research excellence continued to flourish, which impact globally and nationally on health policy and practice
2. The dissension noted by the 2010 SETI review was attributed to a lack of a common vision (with one line of tension running between a goal of conducting research, and a goal of actually providing health services and community education based on research), a leadership vacuum, the erosion of confidence in management, an unclear vision and legacy contribution, and administrative systems and procedures in terms of procurement and finance that undermined rather than supported research. Indeed, the concern with administrative compliance and processes was seen in tension with, and at the expense of, fostering a notion of good science and cutting edge research work.
3. Skewed resource allocations, in terms of organizational intramural priorities, rather than an orientation outward to fund extramural research, in terms of the role as “custodian of all SA medical research”, as well as a high proportion of expenditure on salaries and excessively high expenditure on administration, in the context of a declining baseline grant from DoH.

4. The organizational structure was seen to be outdated, having evolved over time in an incremental manner so that there was duplication and incoherence of units, with little overall strategy or coordination mechanisms.
5. Research productivity was low, with little synergy and collaboration internally within the MRC.

The new president proposed a seven point revitalization plan, and initiated a process of consultation with staff and other stakeholders. At the core of the new vision was a proposal to reprioritize scientific excellence, and to reorganise intramural research in terms of the 10 most common causes of disease and mortality in South Africa. The implication was restructuring, closure and merger of units, to become a "modern research agency" (MRC 2012).

If these challenges accurately describe conditions within the organization at the time of research, they would not be conducive to promoting and supporting interaction with external partners as a priority for the MRC and its scientists. In the following section, we consider evidence from interviews with senior scientists, heads of units and managers, to determine their assessment of organizational conditions at that point in time.

MRC scientists views of the revitalisation process

The lack of a *common vision* within the organisation, and the degree of pulling in different directions without a clear common understanding of the overall vision and goal of the organisation, was an issue raised by a number of interviewees at the time of research. One unit director mentioned that some scientists prefer to compete than to collaborate and work together for the common good:

> I think it has to come from the way people were trained and think of research, now I'm talking from within, because if you have the notion of principal investigator, that is like the US type, you are like a small 'god' you interact differently…but I'll prefer a situation where the researchers are equal and are about teams and working with different components and skills, because that's how you can then interact (Interview Unit Director 2, 2012).

The lack of cohesion and shared common goals were reflected:

> … MRC has a general story which says health doesn't know political borders and you work across borders; but there's no, everybody does their own thing, sounds like a bit too broad but I mean we really do it on a program by program basis, sort of project by project basis (interview Unit Director 4, 2012).

One unit leader was asked to explain where his unit fits and its purpose within the MRC. The following lack of clarity came through:

…I'm talking about MRC yes in this unit as well. We are not, I'm not technically a unit, we sort of straddle, but never mind - we'll call it a unit for today, because we get lumped in sometimes, we get included and sometime not… (Interview Unit Director 4, 2012).

The *leadership vacuum* led to confusion and instability with staff, even those in senior management positions, being unclear whether their interaction with external partners such as government is appropriate:

… in terms of the MRC and these processes it's not easy, I have no degree in communication or some sort of business skill to know how to formalise these processes…now with our stakeholder management there is no such a thing at the MRC. There is not even a strategy that you can say if a Minister contacts me directly, this is what I must do, I must inform A-B-C and D. There is no processes; so that is why I say its, short of being blunt to you, to say it's a chaotic system and there is no processes in place to deal with it. I just deal with it in a case by case basis when it happens I have to guess, suck my thumb and hope I'm doing the correct thing. That's to be perfectly brutal with you (Interview Unit Director 6, 2012).

This led to *erosion of confidence in management*. One of the researchers expressed concern that the organisation had no rewards for being involved in external engagement, which was in tension with achieving other criteria:

No, because I don't get assessed on that, and if I do it there is no reward, but if I don't achieve on the other things there's a punishment, and so I'm not in favour of spending much more time on public engagement assignments. I have one person, she is a professional, she does it [engagement] all the time, and even with her she's getting very disillusioned. It's not a good way to spend time with an experienced scientist, you should have people who are dedicated to that, not research scientists, it's not a good idea (Interview Unit Director 5, 2012).

Likewise, the role of *DoH, as steward* of national health research providing leadership and strategic prioritisation, was recognised as problematic and a major gap. One researcher noted that the DoH has its own challenges, which contributes to a lack of leadership and direction for the MRC:

… and we've not had a strong connection with the Department of Health. I think it's partly the Department has not been very strong and together, I think they have been going through their own issues…

Resource allocation between intra and extra mural research was identified as a perennial problem**:**

…the balance between intramural and extramural has always been difficult to manage as to how much to go, one way or the other and I would say probably the extramural was kind of

> kept constant so inflation deflation, whereas the intramural had a little bit of growth and, yeah, the SETI review sort of saying support of clinical research has dwindled in South Africa (Interview Unit Director 9, 2012).

The revitalization vision proposed by the new president tasked to turn the organization around was permeating down to MRC staff, and units were reviewing their future focus in terms of the new criterion of 'burden of disease':

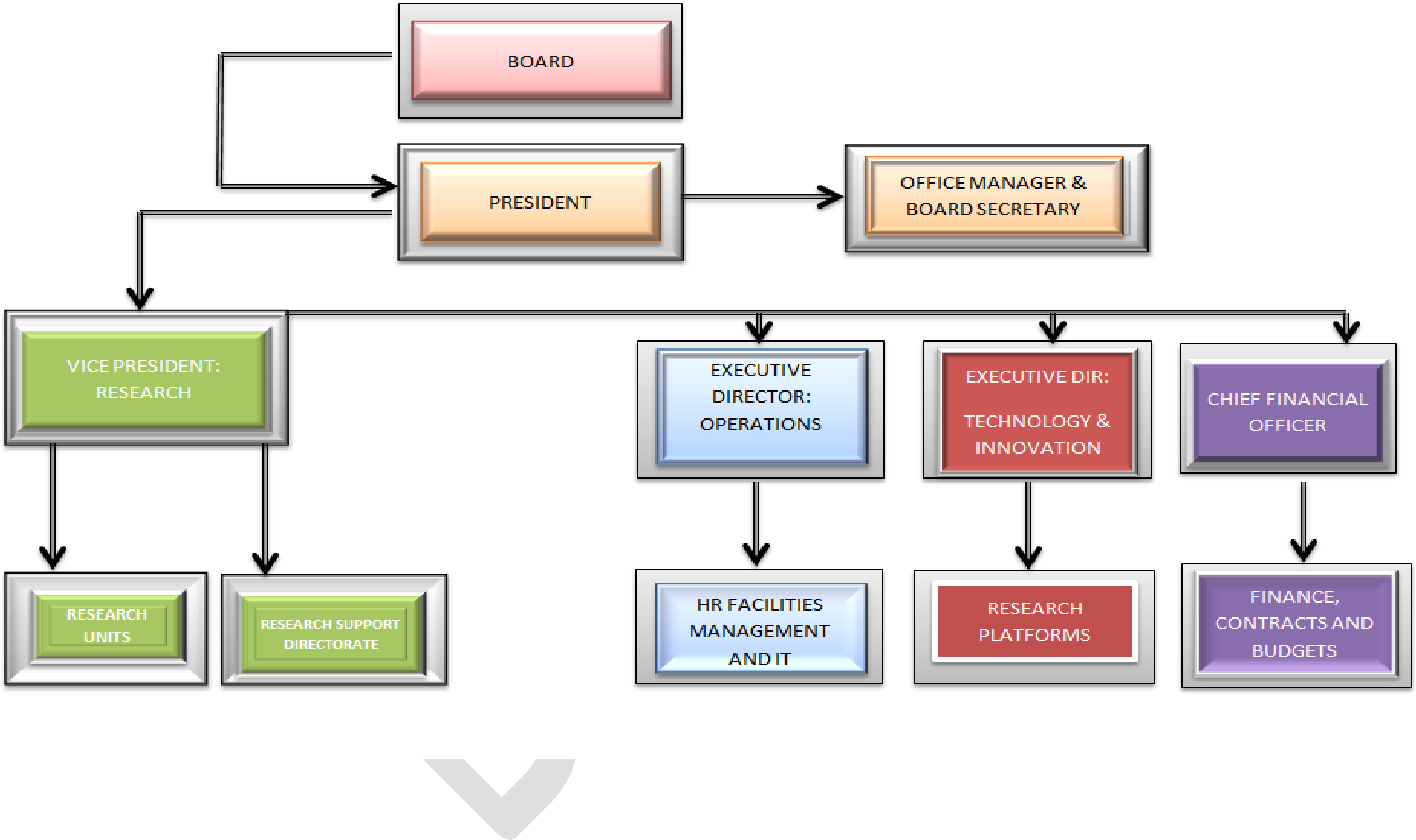
> … how we decide which unit will be prioritised was according to the burden of disease priority globally and for South Africa, so we focus, we have to prioritise, we can't do everything. So *X* is in fact the 3rd greatest risk factor for death and disability in South Africa (Interview Unit Director 3, 2012).

The new vision was likely to promote innovation and exploitation of intellectual property, and hence, greater interaction with government and industry:

> So there is a lot of flux at the moment. However one of the pillars of the new revitalised MRC is innovation. So the innovation centre is being expanded dramatically, both funding wise and scope wise, okay. It's more product related, product focused, in other words we are going to operate like the acronym PDP, Product Development Partnerships, in other words with academia industry and government. We've got substantial funding from the Department of Science and Technology. I mean very substantial, tens and tens of millions (Interview Innovation Centre, 2013).

In the context of organisational turbulence, and an institutional culture in flux, we may expect that patterns of interaction will largely be driven by individual motivations, with minimal organisational support. The following section analyses the approach, structures and mechanisms to promote interaction at the MRC.

Figure 7. 1: The MRC Presidential and Directorate structure 2012/13



Structures and mechanisms to facilitate interaction: An unstructured approach

At the time of research, the MRC had a vertical reporting structure for research management and leadership, as summarised in Figure 7.1.above. All intramural units reported to the Vice President Research, as did the Research Support Directorate, a structure which the 2010 SETI Review criticised as creating bottlenecks. An executive director was responsible for technology and innovation, and research platforms reported directly to him. Contracts were however managed by a different and more administrative internal structure, under the CFO.

From the organisational structural point of view, interface mechanisms do exist, but how they function in practice seemed to be unclear, suggesting a lack of internal coordination and alignment. Interviews with researchers provided divergent perspectives on what internal or external interface mechanisms existed to support and promote engagement. On the question of whether there were specific internal interface structures that lend support for engagement activities, one unit director reflected the standard type of organisational procedures that one would expect in a public research institute, of the kind that would typically be the responsibility of the director of operations:

> Oh yeah! We have the legal office, we have the contracts and budgets that looks after the, they have to draw up the statements, they have to look at the cash flows that's in the project, they ensure that I do not go and buy in China in the project, and that I only work what's in the contract. There's an HR element, there's a budgets and contracts, there is a legal, and don't forget the support services you know like your IT…(Interview Unit Director 1, 2012).

Unit directors pointed to a specific structure, the Strategic Research Initiatives, which is supposed to be responsible for promoting links with external partners:

> Within the MRC there is one strategic unit that is meant to make sure that there is interaction within the organisation and also externally. Because how do they do that, sometimes they identify calls for proposals focusing on specific subject matters, let's just say HIV, but then because they are in a strategic unit, then they are able to see which units can participate, because they are an oversight (Interview Unit Director 2, 2012).

> So if you looking at X's role, it's a strategic research initiative, that is very much about links between the MRC and the external parties but that's really largely in relation to specific programs and typically large scale… These other things, no, there's not a specific support structure (Interview Unit Director 4, 2012).

A senior manager explained the origins and purpose of the strategic research initiatives, reflecting that it was an internal interface mechanism to create greater internal coherence in responding to external opportunities:

> So it was around 2004 that I suggested this position to the executive committee of the MRC because I found that there was gap in the organisation in terms of initiatives that we could sort of looking into, that we want to cover. So basically the idea was to do some forecasting exercising, scenario planning and to sort of look at future research. So we needed to start looking at how we could get people to start already thinking about research ideas and so forth (Interview Executive 1, 2012).

The 1997 SETI Reviews recommended that the Technology Transfer Office should be strengthened and made transparent to all participants. In response, the MRC employed an IP lawyer with a scientific background, and established a Centre for Strategic Management of IP as well as IP policy. As part of this process, the MRC developed an Innovation Centre to ensure that discoveries stemming from MRC research are captured and translated into usable technologies for the MRC, its stakeholders and the public at large. Some respondents questioned whether these interface mechanisms were functioning optimally:

> Patents is something we looking at, we have a good innovation office that looks into that but frankly I don't think we are at the level of international organisations, we don't have the kind of skill base they have, equipment, money to exploit these things. So I think it's nice to have but I don't think there's much coming out of our patenting office (Interview Executive 1, 2012).

Other unit directors shared similar sentiments concerning internal interface structures that are meant to promote engagement or to give direction, but are not effective:

> Well those things exist but they've never assisted us in any way. So, I'm honest with you – so we have an innovation centre of which it lent no assistance to us in terms of raising the funds for the innovation, if I can give you a typical example. So instead of going to the US and buying an App that was made and customised for the US people, you have a platform in South Africa where you can do this App development. Now to get to the App development stage you need some sort of mechanism, it's almost like building a website, you need a template, you need funding right?...(Interview Unit Director 6, 2012).

However, the Innovation Centre was undergoing major change at the time of research, as part of the revitalisation strategy change management process:

> So there is a lot of flux at the moment. However one of the pillars of the new revitalised MRC is going to be innovation. So the innovation centre is being expanded dramatically both funding wise and scope wise, okay. So our scope is very it is becoming much broader. It's more product related product focused, in other words we are going to operate like the acronym PDP, Product Development Partnerships in other words, with academia industry and government. We've got substantial funding from the Department of Science and Technology. I mean very substantial, tens and tens of millions. Okay, in the next couple of, 3 years (Interview Innovation Centre, 2013).

The National Collaborative Research Programmes is one of the platforms within the Technology and Innovation Directorate, a result of a consortium based research initiative under the direct control of a senior executive. It could function as both an internal interface mechanism, organising researchers with similar or cognate interests, and an external mechanism linking them to external knowledge partners. We have information on its origins and intent, but not on how effective it is as a mechanism:

> So the idea of setting up this program was initially to align the MRC's research with the key priorities in the country with the particular focus on the non-communicable disease…so that was the overall idea to serve as an umbrella structure, maybe to actually gather researchers across the country and even beyond to really address major issues relating to non-communicable disease in the country, that's the overall idea (Interview National Collaborative Research Program, 2013).

There are long-standing health related platforms that assist in facilitating engagement by setting research priorities jointly and playing a brokerage role:

> …so you have the provincial health research committee that's the committee that is supposed to be saying this is the agenda for the Western Cape and these are the priority areas and so on…So then it's a way of bringing about this collaboration…but there's also the national health research committee like the one led by professor X. So those are platforms that actually assist us as well in terms of facilitating engagements (Interview Unit Director 2, 2012).

One pattern that stands out is that these internal interface mechanisms tend to operate in relation to key priority research areas, involving specific groups and individuals, and not collaboration broadly across the entire organisation. Some unit directors reported that they had no interactions *within* the MRC, except with management, and externally, with universities nationally and internationally on a collaborative basis. For example, when asked about internal interface structures such as IP offices or external structures such as incubators, one unit director responded: 'Yeah, I run all that through the university' (Interview Unit Director 5, 2012).

The interviews thus reflected the concern of the 2010 SETI review, of internal fragmentation and the tendency to work in silos. Our research identified few formal structures and mechanisms for internal coordination that were widely seen as effective. As the MRC has a very uncoordinated structure, and has been in flux over the past few years, senior staff members reported that they have to develop their own means of 'making things happen', through their own networks. The strongest organisational trend is thus that individual research units work in silos. Nevertheless, since the 2012 strategic plan, there has been a move on the part of senior management to foster connectivity and encourage collaborative research between units on a larger scale:

> The MRC Strategic Plan spoke to collaborative research as one of the emerging priorities, MRC has been focusing on individuals who are unit directors and looking at silo operations; so its nutrition, diabetes, its HIV – we felt that if they collaborate the benefits are much greater than individual outputs…. So it's transdisciplinary, across institutional, across multidisciplinary boundaries, so that kind of idea was something that we wanted to explore further…and my mandate was to put together what we call collaborative research groups, as well as national collaborative research groups (Interview Executive 1, 2012).

External interface structures that work as channels of interaction

Similarly, many respondents were aware of the existence of external interface structures, but some were not sure whether these structures are still in existence:

> …I think it's been tried in the MRC, I mean there was a research translation office at one time, I'm not sure, I don't think it exists anymore, I think as an organisation we could do a lot better…There are times for example when there might be a program and the school kids and they ask different units to come put up posters and things like that but it's quite ad hoc and I think it's not something the researchers rush towards doing, seeing it as nuisance probably (Interview Executive 2, 2012).

A number of mechanisms were put in place to interact with communities, based on the recommendations of the 1997 SETI Review. One area relates to more effective communication and dissemination of specialised research support services, with much reported activity. Typical mechanisms are websites, the establishment of information centres at rural universities, packaging information for NGOs, and developing health informatics courses. A Radio Production studio reportedly offered science-related programs developed by MRC to be broadcast on community radio stations, but this was closed down as part of the changes introduced by a new CEO appointed in late 2013 to take forward the revitalisation process.

Some MRC units had a dual role of providing a cross-cutting form of service to other MRC units, while also conducting their own research. For example, the Biostatistics unit provides essential statistical analysis services that shape the nature of the team's interaction:

> So its interesting that when the MRC was founded in 1969, that one of the first personnel that was appointed to the MRC was this Statistician. So the MRC since that time had a commitment to have a statistical group within MRC to support the internal MRC research units and then the external parts of the MRC. So I think we are one of the units that work across most of the units in the MRC with most researchers at most universities, and we have offices in Cape Town and staff in Pretoria and Durban so to have a regional presence for the units that are situated there. So in that sense we are a research unit, so we have the same privileges of other research units. So that is in contrast to a service unit. So that you are here to do statistical analysis of projects, but we strategically decided to become a fully-fledged research unit so that we can engage with outside stakeholders and research groups that don't have any other MRC link (Interview Unit Director 7, 2012).

The key incentive and institutional mechanisms to promote interaction

Most of the incentive mechanisms identified only tangentially promote or support interaction:

- The SETI reviews represent a mechanism for regular reflection on the achievement of strategic goals and setting targets, and may provide an opportunity to incentivise engagement.
- Capacity development programmes build capacity at every stage in the value chain, and promote involvement with external partners: from high school students on MRC open days, BSc students on work study programmes, master and doctoral students as well as career development awards for future unit directors.
- Leadership of the Comprehensive National Health Research Policy was transferred to DOH and the ENHR Committee serves as a mechanism for interaction across government.

The majority of interviewees could not identify any incentive mechanism within the organisation that could promote engagement for individuals. It was however, linked to performance appraisal, albeit indirectly:

> No direct reward, it comes under the performance appraisal at the end of the year, you know the more you do that [interactions or engagements] the more the output you will have and the better you will do in performance so indirectly there is a reward yeah…I mean contacts and friendship you know and moving onto the next grant and that sort of thing. So that would be important too, yeah (Interview Unit Director 5, 2012).

This sums up a general view amongst researchers at the MRC that interactions are important, and can be seen as implicit requirements for success within the organisation. Furthermore, engagement is seen as a practice that depends on the nature and requirements of ones duties and the nature of the research unit and how it functions. Another unit director put it this way:

> …So engagement with external social partners is based on priorities, setting the need for engagement earlier on, because you see, if you want to influence policies, this is what we always do…You need them to understand what you are doing and then they will listen to you, policy makers or program managers or even people on the ground. So the interaction there is very mechanical, but here it's subject matter related. They understand what you are trying to do and are more likely to respond to what you say. So we interact on the basis of need, priorities, feedback, engagement also (Interview Unit Director 2, 2012).

Engagement and feedback were key terms for this unit since influencing of policies is seen as crucial. For other units in contrast, engagement was seen as wasting valuable research time:

> No, because I don't get assessed on that, and if I do it, there is no reward; but if I don't achieve on the other things, there's a punishment; and I'm not in favour of spending much more time on public engagement assignments. I have one person, she is a professional, she does it all the time and even with her she's getting very disillusioned. It's not a good way to spend time with an experienced scientist, you should have people who are dedicated to that, not research scientists, it's not a good idea (Interview Unit Director 5, 2012).

This view was shared by others, that engagement is important, but requires skills, and hence should have dedicated well trained professionals, while research scientist should be left to do what they are best at. Disruption to the scientific process was seen as a major obstacle militating against engagement activities:

> One of the obstacles is you get different personalities from different institutions who suddenly come on board and they want to hijack the whole process and it pushes sometimes into directions that we as scientists do not want to, because on a personal level we have fantastic collaboration. I've had it in the past with some institutions that I worked with, and then suddenly the scientist sees money and they change the whole, yeah! I had it. So in the end we had to withdraw from the contract because you know they got greedy. I'm sorry to say it but that's the honest truth (Interview Unit Director 1, 2012).

Other obstacles to engagement raised were competition due to lack of a shared vision between an MRC unit and an external partner, as well as lack of funding and issues of supply chain management, which seemed to be a source of concern.

Individual drivers of interaction

If there are few clear enabling structures or steps for achieving effective internal collaboration or external interaction, engagement will primarily depend on individuals and their experience. Asked how interaction is promoted or supported within his unit, one unit director highlighted the significance of individual scientific reputations as a driver: "It's all done by personal contact, originally, initially and a lot of that happens by meeting people at conferences and then from there it goes word of mouth and by networking" (Interview Unit director 2, 2012). This was not unique to the specific unit:

> Yes well we all do, all our senior people here do their own networks, its not only me. I couldn't possibly do it all on my own. So you know I have 3 or 4 senior people who all do that themselves as well as with me. So often a lot of the contacts are initially made by me and then passed on where its suitable for their expertise and then after that they take it and then run with it on their own (Interview Unit director 2, 2012).

Most of the networking is driven by the need to access research grants, which often require collaboration with international partners as a condition, or what one interviewee called 'unwritten grant conditions'. Engagement with funders was thus a key form of external interaction identified by MRC scientists. For example, asked what terms he would use to describe his interactions and engagements within the MRC and external social partners, one unit director highlighted the widespread conception of partnerships with funders, given the open-ended nature of much of the research:

> You know it comes in different levels, say for instance when we look at engagement with a funder, you know I always talk about, not a funder, a sort of grant recipient relationship, we

> want to talk about partnership. Now the reason why I emphasise on the issue of partnership is simply because the type of work that we do is really new. It's really unpredictable, but if you are going into a sort of partnership with your funder, you begin to share with the funder problems that are coming through the research. He does not stand up there and say 'I funded you, so I'm looking at the outputs', because those outputs would be determined by the problems that really are found in terms of any other research. Research is very unpredictable, I may say to you I want to start today, due to circumstances that may be beyond my control I start you know a year later (Interview Unit Director 3, 2012).

This suggests that the nature of a unit's research programme could shape the kind of partnerships and relationships the scientists enter into. For some units similar to the one discussed above, the notion of 'partnership' describes a relationship between funder and grant recipient whereby both parties share the collateral damage or liabilities of research.

We conclude that at the time of research, the MRC in effect had an unstructured approach to promote and support interaction, with activity driven by individual academic champions and senior managers.

How do MRC scientist understand interaction?

At the time of research, the MRC consisted of units operating in an uncoordinated way, and not strongly sharing goals and clear institutional policy. This means that there were likely to be multiple conceptions of interaction, and diverse types of relationships, as we began to illustrate in the previous section.

Given the unstructured and coordinated organisational approach, there tended to be a unit-specific approach to identify partners, intrinsically related to the research focus. When asked what terms are used to describe interactions with external partners within the MRC as an organisation, one senior manager elaborated the high level view:

> Well it depends on the nature of partner, the partner could be research collaborator, a funder or someone who shares mutual interest in terms of research. So it depends on the nature of interaction. So our scientists by and large collaborate on research projects with partners, either to *fulfill a funding requirement or because they have a mutual interest* in a certain area and it could be non-financial or it could be part of bigger team where they interact with partners… So stakeholder relations would be – I would say collaborators is the right word, stakeholders is more upwards, you know what I would term upward

> engagement. Collaboration would be at different levels with peer groups, with communities, with medical, the industry, and academia…That's the right term, these are collaborators, stakeholders are mainly the Department of Health and parliament and stuff (Interview Executive 1, 2012 emphasis added).

Note the significance of funding and disciplinary research interests as drivers of interaction. Another unit director confirmed the suggestion that most partnerships relate to research collaboration or funding relationships:

> I think it's within and also outside, because remember we also work with universities [collaborative research]. So the terms that sort of come to the fore are usually partnerships and collaborations and formal partnerships in most of the cases especially where funding is involved because I'm currently working with X university and if I don't have a formal agreement, then it means I can't pay them or they can't pay me. So its partnerships, largely formal, but we also have informal partnerships because it's about interest. There's no need to talk to someone else who's interested in other things that you are not interested in (Interview Unit Director 2, 2012).

Other units similarly identified their university counterparts and other academics as their main partners:

> We do collaborate with them, it's a one on one in product development, and that normally spins out from maybe an academic interaction which becomes then a, if I can use the word, commercial application. Where we see there is a commercial value then basically the different innovation centres from the university or the MRC collaborate, where we do an audit to see if this could become a program or is just an academic exercise (Interview Unit Director 1, 2012).

This appears to be a distinctive feature of the MRC, that most interaction is viewed as collaboration with academic partners or "stakeholder relations". There is little formal institutional policy or debate about the need for engagement and social responsiveness of research, perhaps because of the MRC's intrinsic focus on applied research in relation to enhancing health and the quality of life, or perhaps because of a tendency to collaborate with academic partners. The following section therefore moves on to consider the evidence of the patterns of interaction reported in the practice of scientists.

Patterns of interaction with external stakeholders in the practice of MRC scientists

A fifth of scientists do not engage

The population of intramural scientists at the MRC was 451, and 283 researchers participated in the survey, a response rate of 63%. Of note is that 73% of the sample was female. Some 79% of the sample indicated that they extend their knowledge to the benefit of external partners in some way, a rate comparatively lower than the other science councils surveyed.

Over a fifth, 21%, indicated they do not engage. Those who do not engage were slightly more likely to be African and women. Scientists and senior scientists were slightly more likely to report no engagement than heads of units and managers. Those who had diplomas and certificates or bachelors degrees were also less likely to engage than those with higher levels of qualifications. Almost a third, 39% of those who do not interact were based in laboratory “platforms”, that is 23 of the 85 scientists based in that type of unit. It is thus evident that the more junior and technical staff do not engage.

Knowledge partners most common

The trend distilled from our interviews is confirmed by the survey data - the most frequently reported partners of the MRC scientists who engage were South African universities, funding agencies and science councils, their knowledge partners (Table 7.1). Thereafter, the most common partners are health related – clinics, local communities, and hospitals - at primary health levels slightly more frequently. We include a wider range of partners in Table 7.1, as a reference point for the frequency of interaction with other clusters of partners discussed below.

Table 7.1: The nature of external partners at MRC

Social partners		Engaged					
		Frequencies				WTotal	WAI
		1	2	3	4		
1	South African universities	27	36	59	101	680	3.05
29	Funding agencies	37	40	63	83	638	2.86
2	South Arican science councils	39	53	66	65	603	2.70
3	Clinics and health centers	62	43	51	68	573	2.56
4	International universities	51	57	66	49	559	2.51
5	A specific local community	74	31	51	68	561	2.50
6	Hospitals	62	53	46	62	554	2.48
7	Individuals and households	77	37	53	57	538	2.40
8	Provincial government departments or agencies	64	56	61	43	531	2.37
9	National government departments	64	66	49	45	523	2.33
10	Non-governmental agencies (NGOs)	69	56	55	44	522	2.33
11	Local government agencies	69	58	57	40	516	2.30
12	International science councils	78	59	55	31	485	2.17
13	Community organizations	94	54	42	34	464	2.07

A widespread of diverse partners

To investigate the nature of interaction with diverse partners, Figure 7.2 shows the results of a correspondence analysis between types of partners (P blue spherical dots) and types of relationships (R red triangular dots). The dimensions on the correspondence map explain 58% of the variance between the points, with Dimension 1 (x – axis) explaining more variance at 34%, 24% explained by Dimension 2 (y- axis).

The most striking feature is that the partners and relationship types are more widely spread on the factor map for the MRC, in contrast to the other science councils. The map for Mintek for example, was strongly concentrated around the point of origin and reflected a high degree of homogeneity in the pattern of interaction. This suggests a stronger degree of diversity in the practice of MRC scientists, either between units, but even within the practice of individual scientists, depending on the demands of a project. Interviews can illuminate this trend:

> Okay I think we should define who the external partners are, and I think it's better for me to wear my unit's hat. It varies, we have partners at multiple levels. If you look at the international level we work quite closely with the WHO and UN Office of X, that's just two examples of international agencies…Okay, so lots of national partners, I provide technical input. There's something called inter-ministerial committee on X, so I've been advisor to the technical committee and presented information on what should they do around things like banning X or whatever (Interview Executive 2, 2012).

> …So two areas the research area I work in is evaluation of A, which needs working with departments; and then the other is Y, and that absolutely requires working with multiple people; we've got 3 areas of work and one of those is networking, coordination, again because of the particular role of the MRC and that role is a regional role as well (Interview Unit Director 4, 2012).

> Well it depends on the nature of partner, the partner could be research collaborator, a funder or someone who shares mutual interest in terms of research. So it depends on the nature of interaction. So our scientists by and large collaborate on research projects with partners, either to *fulfil a funding requirement or because they have a mutual interest* in a certain area and it could be non-financial or it could be part of bigger team where they interact with partners… (Interview Executive 1, 2012 emphasis added).

The overall pattern thus confirms our analysis, that there are multiple conceptions of interaction and likely to be diverse types of relationship.

There are two ways in which to interpret the points on the factor map (Figure 7.2). Firstly, the stronger or weaker associations can be understood by analysing the distance between the associations (point P and point R) along Dimension 1 (which explains more variance). Secondly, the more common or atypical associations are identified by analysing how close the associations are to or from the point of origin.

Figure 7.2: The correspondence analysis map of the partners and relationship types

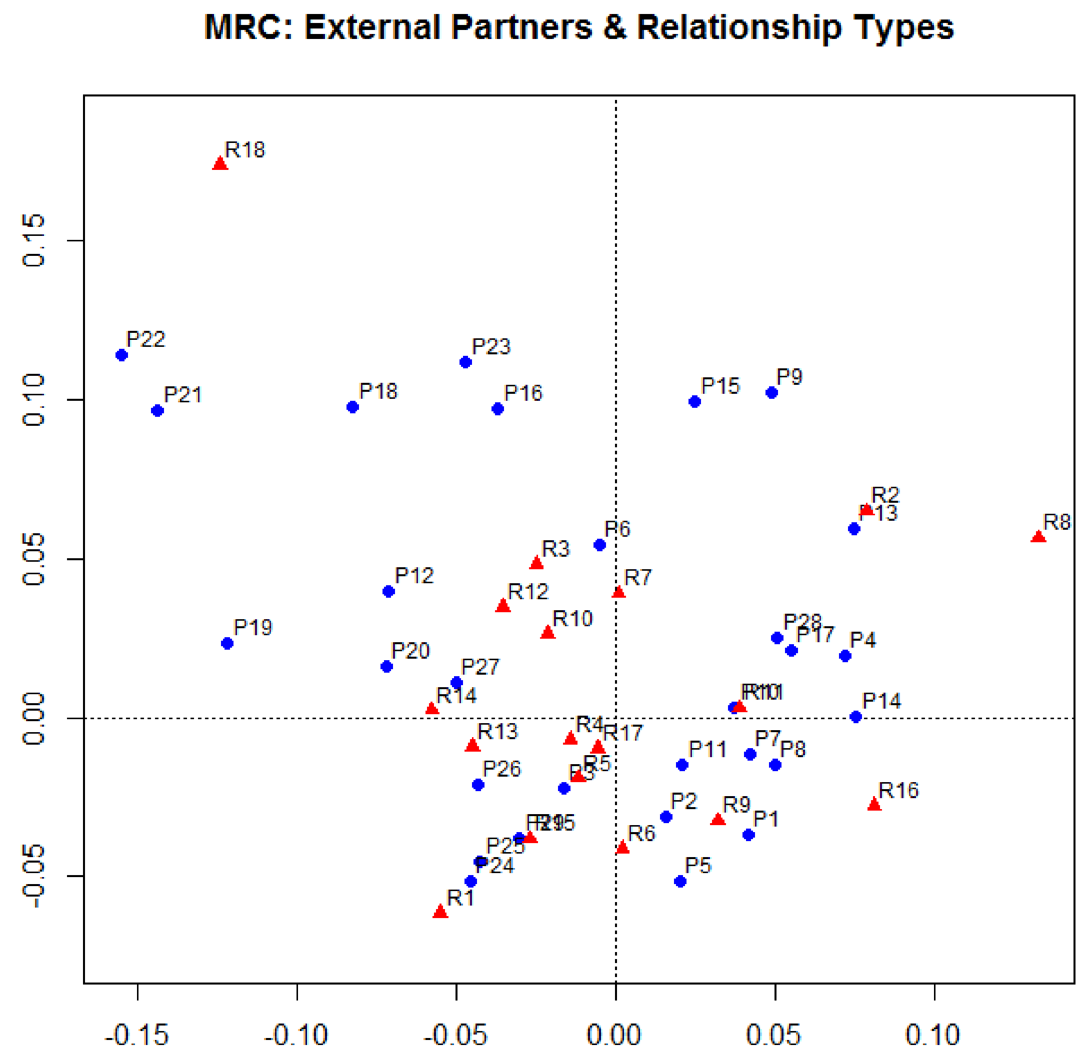


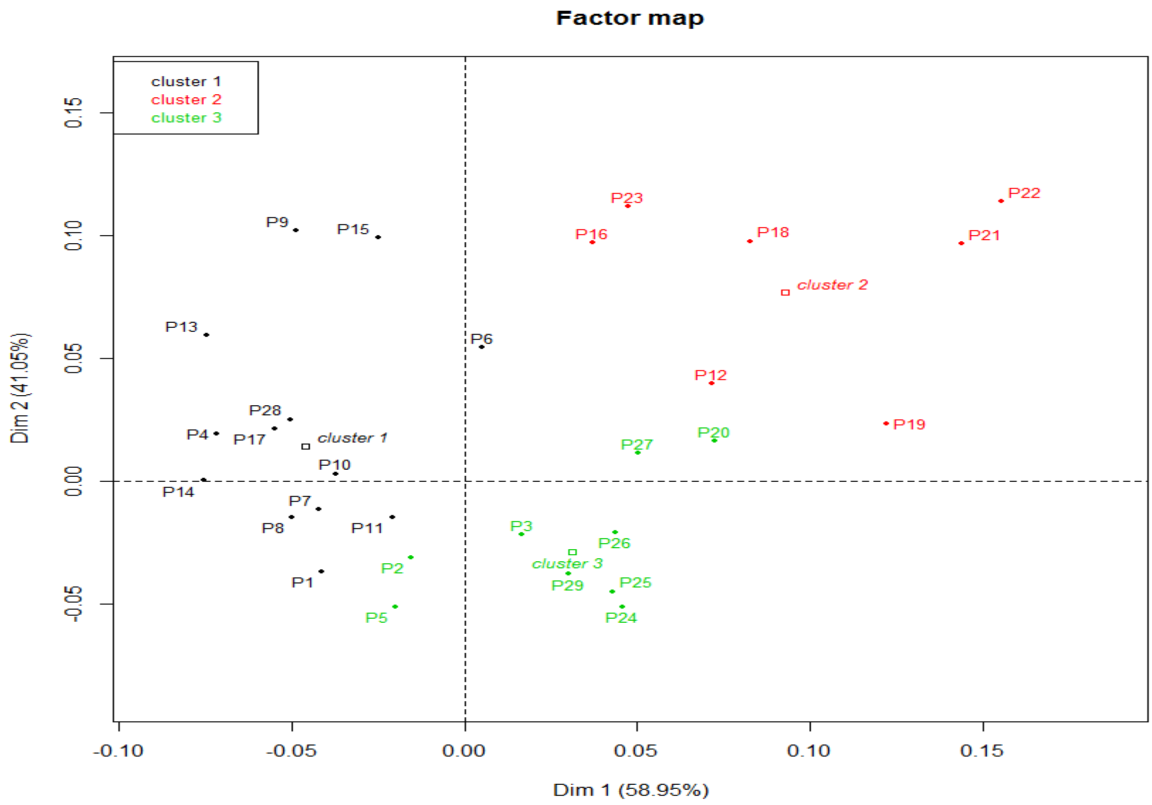
Table 7.2 summarises a number of the close associations observed, to show the types of relationship most likely to characterise interaction with specific partners.

Table 7.2: Partners and associated relationship types

When the MRC partnered with	The possible relationship types were
South African universities (P24) and/or International universities partners (P25)	Educating post-graduate students so that they are socially responsive (R1)
Funding agencies (P29)	Collaborative R&D projects (R15)
South African Science Councils (P26)	Continuing education or professional development (R4), or customised trianing and short courses (R5), and/or technology transfer (R13)
Provincial government or departmental agencies (P2) and/or Schools (P5)	Policy research and advice (R6)
National government departments (P3)	Continuing education or professional development (R4), or customised training and short courses (R5), and/or participatory research networks (R17)
Developmental agencies (P11) and/or individuals and households (P7)	Designing, prototyping and testing of new technologies (R9)
A specific local community (P8), community organisations (P14) and/or local government agencies (P1)	Community-based research projects (R16)
International Science Councils (P27), multinational companies (P20), or tade unions (P12)	Contract research (R14), design and testing of new interventions or protocols (R10), and/or research consultancy (R12)
National regularoty and advisory agencies (P6)	Collaborative curriculum design (R3) or expert testimony (R7)
Hospitals (P28), Religious organisaitons (P17), Clinics and health centres (P4), and/or Civic associations (P13) welfare agencies (P9) Social movements (P15)	Voluntary outreach programmes (R2) and/or clinical services or patient care (R8)

To reduce the complexity of the analysis and to discern simpler patterns, we conducted cluster analysis, and produced a factor map of the partners (Figure 7.3) that are strongly associated with a similar profile of relationship types, and vice versa, clusters of types of relationship (Figure 7.4).

Figure 7.3: Correspondence analysis by partners

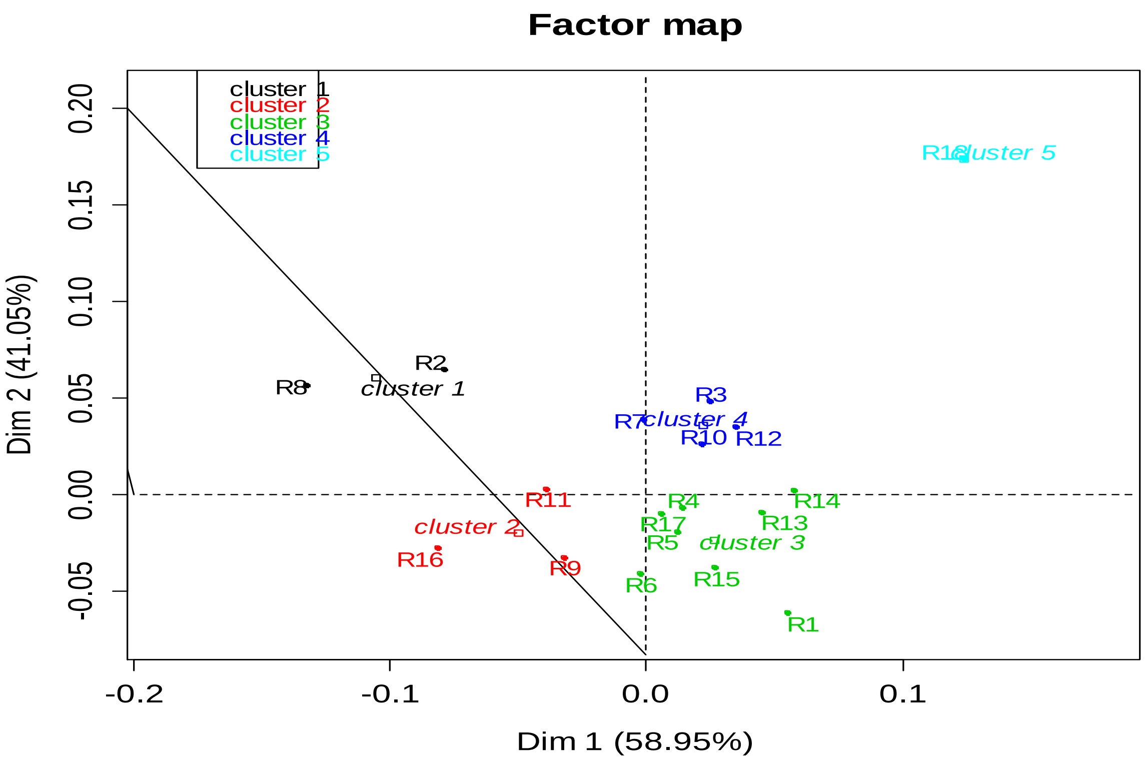


There are three distinctive clusters of partners that reflect the MRC mandate and focus. Cluster 1 is spread most closely along Dimension 1, and represents a set of partners that are strongly associated with each other. It consists of a large number of partners related to primary health activities: community organisations, NGOs, national regulatory agencies, local community, development agencies, local government agencies, religious organisations, clinics and health centres, hospitals, civics, welfare agencies and social movements. Cluster 3 represents a set of partners more strongly associated with dimension 2 but still close to dimension 1, related to knowledge generation and innovation activities of MRC: national government, provincial government, SA science councils, funding agencies, international univeristies, SA universities, international science councils, multinational science councils, and schools. The WAI analysis in Table 7.1 suggests that there is more frequent interaction in relation to Cluster 3 partners.

Cluster 2 consists of a set of partners that are not typical of MRC, situated at a distance from both Dimension 1 and 2, and with very low WAI values, indicating interaction in isolated cases only:

SMMEs, trade unions, small-scale farmers, large firms, political organisations, sectoral associations and commercial farmers. Analysis of these "outlier" points in Figure 7.2 highlights where there may be niche or emergent activity. For example, industry related partners (P18, P23, P22, P19, P21) are less frequent at MRC, but when they do occur, it is associated with the significant relationship type of joint commercialisation of a new product (R18), which could contribute to the health mandate or to the mandate to advance global competitiveness.

Figure 7.4: Correspondence analysis map by types of relationships



There are five clusters of types of relationship, which reflects the diverse ways in which scientists may interact with the same set of partners. Table 7.3 reflects the WAI of types of relationship, to assist in the interpretation of the frequency of the types of relationship in each cluster. The most frequent types of relationship are distinctive to the MRC, with design and testing of interventions and protocols, collaborative R&D, monitoring and evaluation and community-based projects the most frequent.

Table 7.3: WAIs of type of relationships

Relationships		Engaged					
		Frequencies				WTotal	WAI
		1	2	3	4		
9	Design and testing of new interventions or protocols	30	20	57	114	697	3.15
15	Collaborative R&D projects	35	29	60	97	661	2.99
11	Monitoring, evaluation and needs assessment	44	36	61	80	619	2.80
16	Community-based research projects	49	35	58	79	609	2.76
4	Continuing education or professional development	35	53	70	63	603	2.73
17	Participatory research networks	40	47	71	63	599	2.71
1	Education of post-graduate students so that they are socially responsive	54	34	63	71	595	2.68
6	Policy research, analysis and advice	50	42	63	66	587	2.66
5	Customised training and short courses	38	68	61	54	573	2.59
14	Contract research	59	37	60	65	573	2.59
12	Research consultancy	52	53	59	57	563	2.55
10	Design, prototyping and testing of new technologies	61	51	57	52	542	2.45
13	Technology transfer	76	48	54	43	506	2.29
8	Clinical services and patient or client care	103	32	30	56	481	2.18
3	Collaborative curriculum design	87	62	46	26	453	2.05
2	Voluntary outreach programmes	95	51	48	27	449	2.03
7	Expert testimony	104	50	42	24	426	1.94
18	Joint commercialization of a new product	140	37	24	20	366	1.66

Closest to the point of origin on Figure 7.3, and including the largest number of points, is Cluster 3, which reflects the significance of research and innovation activity with the knowledge generation partners (namely Cluster 3 partners): contract research, technology transfer, continuing education, customised training, participatory research networks, policy research, collaborative R&D and education of post-graduate students. These are in the middle range in terms of frequency, occurring on a moderate scale, but are the strongest pattern of association at MRC.

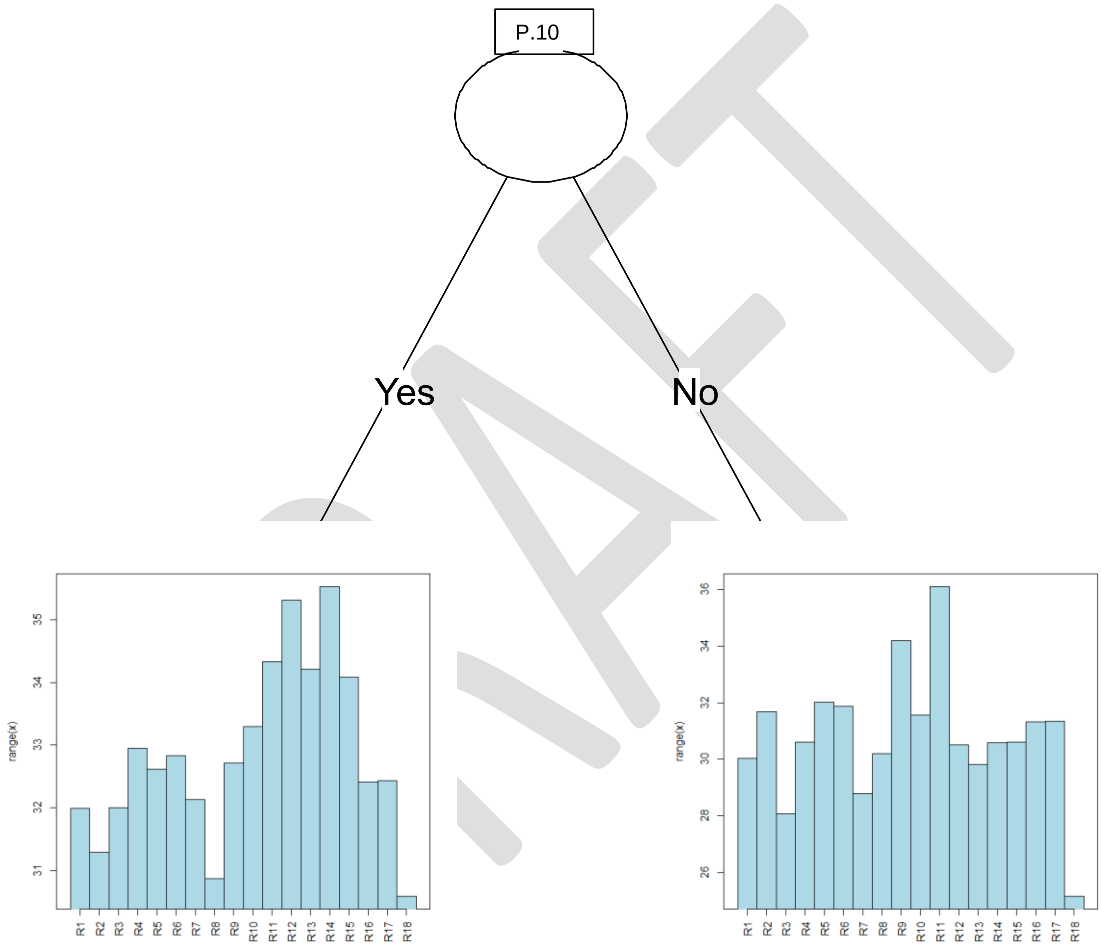
Cluster 2 lies along Dimension 1, and reflects the primary health oriented types of relationship that are most frequently reported: monitoring and evaluation, community based research projects and design and testing of new interventions or protocols (R11, R 16 and R9).

Cluster 4 lies close to Dimension 2 and along Dimension 1. It is not easy to interpret, but seems to be oriented to government partners in the health sector, at different levels: expert testimony, design and prototyping of new technologies, research consultancy and collaborative curriculum design (R3, R7, R10 and R12). Cluster 1 is the furthest from both dimensions, and includes voluntary outreach and clinical services (R2 and R8), types of relationship that are atypical for most MRC scientists.

The classification analysis for the MRC scientists on relationship types

Further insight can be gained from Figure 7.5 below, which shows the result of a classification tree analysis. It reveals that the MRC scientists are split simply in a two-fold manner by P10, that is, whether they interact with NGOs (125 scientists) or not (99 scientists). Inspection of the types of relationship associated with each node reflects a very different pattern on the right and on the left hand sides.

Figure 7.5: Classification tree of the splitting by partners on relationship types



Those who do not interact with NGOs (left hand side) more frequently reported that they are engaging in the knowledge generation and innovation types of relationship included in Cluster 3: contract research, research consultancy, monitoring, evaluation and needs assessment, technology transfer, and collaborative R&D types of relationship. In contrast, those who do interact with NGOs (right hand side) more frequently reported primary health oriented types of relationship included in Cluster 2: monitoring and evaluation, design and testing of new interventions or protocols, customised training and short courses, policy research, analysis and advice and voluntary outreach programmes. Monitoring and evaluation is clearly very significant at MRC, and takes diverse forms for scientists in different fields and interacting with different kinds of partners.

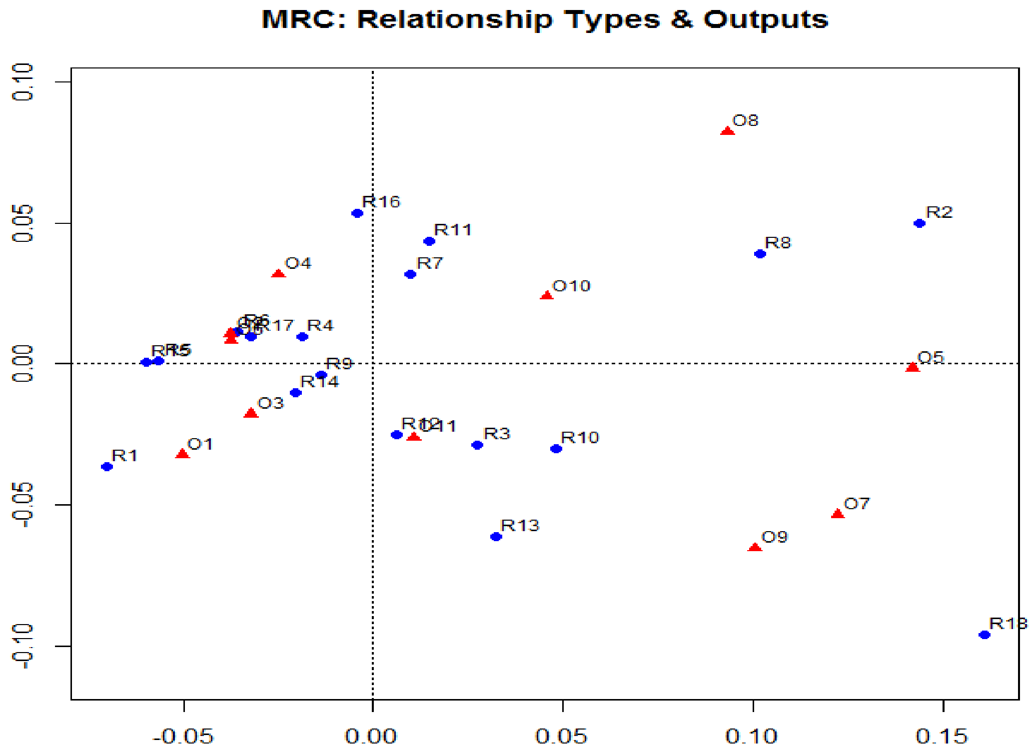
Taken together, this analysis suggests that there is a diverse pattern of interaction at MRC, with a wide spread, given that interaction is strongly driven by individual scientists and units in different fields. However, two main clusters of activity can be discerned. The one is related to a primary health mandate, and the other, to a knowledge generation and innovation mandate. There are also emergent niche clusters of interaction on a very small scale.

What are the outputs of this pattern interaction?

How is this pattern reflected in the outputs of interaction? What stands out at MRC relative to the other science councils is that the most frequent outputs are academic publications (WAI=3.2), and scientific collaboration (3.16), rather than reports, policy documents and popular publications (2.96) which are the most frequently reported at Mintek, CGS and ARC.

Figure 7.6 below reflects the results of the correspondence analysis of the association between the diverse types of relationship and outputs.

Figure 7.6: Correspondence analysis of the MRC relationship types to outputs



Again, the points representing relationship types and outputs are widely spread across the map. Starting from the left side of the vertical axis in the bottom left quadrant, the relationship types of design and testing of new interventions or protocols (R9) and contract research (R14), are closely associated with each other, and the most closely related output is dissertations and post-graduates (O3 and O1 which is also closely associated with R1, education of post-graduates). This provides insight into the nature of partnership with knowledge partners, which involve post-graduate students and the training of the scientific workforce.

In the top left quadrant, relationship types of continuing education or professional development (R4), customised training and short courses (R5), collaborative R&D projects (R15), policy research (R6) and participatory research networks (R17) – those grouped in Cluster 3 (Figure 7.3) - are most likely to produce the outputs of scientific collaboration (O6), academic publications (O2) and slightly less strongly associated, reports, policy documents and popular publications (O4). This alludes to the significance of the knowledge generation and innovation activity pattern for achieving the MRC's main mandate as a science council.

In the bottom right quadrant, the relationship type of research consultancy (R12) is closely associated with and therefore likely to produce the output of scientific discoveries (O11). Collaborative research design (R3), design, prototyping, and testing of new technologies (R10), and technology transfer (R13) are also located in this quadrant, although further away from the point of origin and (O11), so could also possibly produce scientific discoveries.

Another association in this quadrant, but further away from the point of origin is the relationship type of joint commercialisation of a new product (R18) and the outputs of spin-off companies (O7) and/or new or improved products (O9). Although scientists at the MRC are less likely to interact with partners in this way, it reflects a niche trend with a significant output in terms of national science and technology, and health, policy imperatives.

In the top right quadrant, we reflect the primary health oriented outputs, where the relationship types of community-based research projects (R16), monitoring, evaluation and needs assessment (R11) and expert testimony (R7) are closely associated with O10, new or improved processes (such as treatment protocols). In addition R16 is close in distance to O4, the output of reports, policy documents and popular publications that result when MRC engages with partners on community-based research projects (R16). The relationship types of clinical services and patient or client care (R8) and voluntary outreach programmes (R2) could possibly produce community infrastructure and facilities (O8) as an output. The fact that the primary health oriented outputs are in opposite quadrants from the knowledge generation and innovation outputs provides further evidence for a split in the practice of MRC scientists.

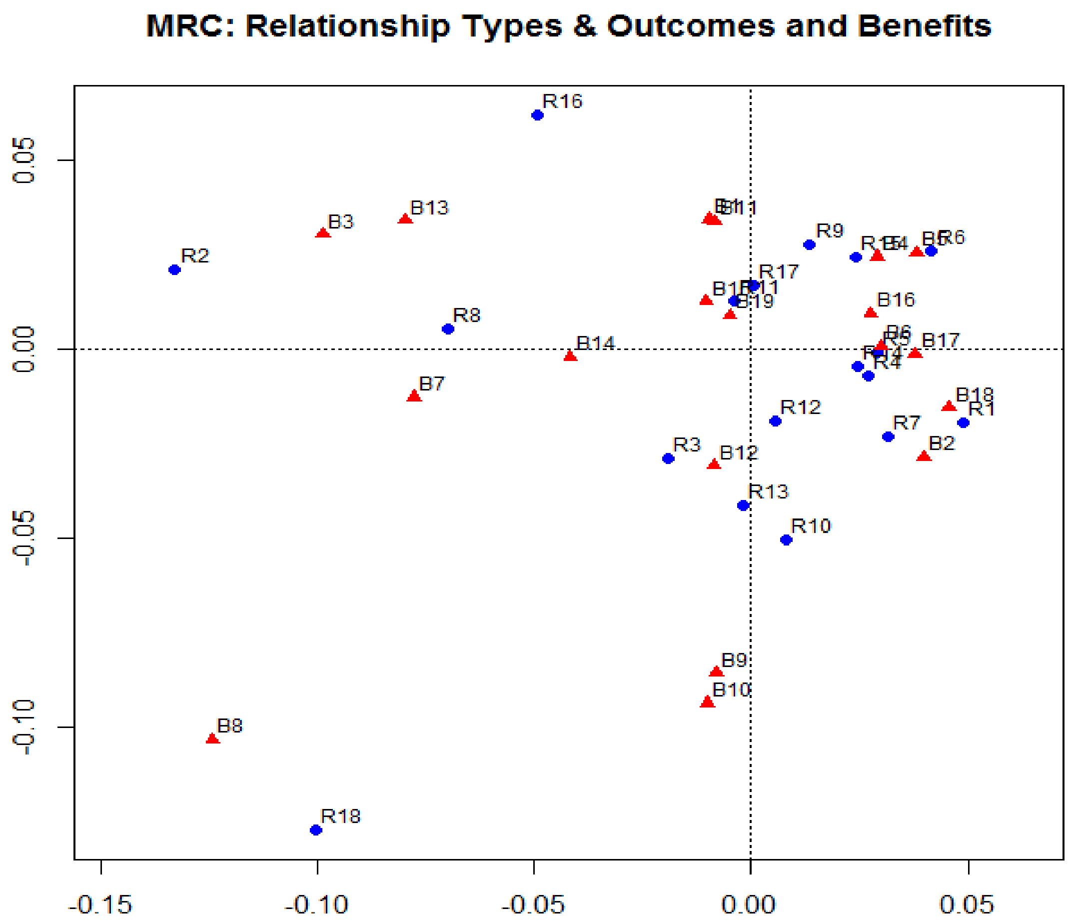
This is confirmed by a classification tree analysis (not shown). The main split was on post-graduates (O1). Those for whom post-graduates were not an output, suggesting that they are not interacting with universities as partners, were more likely to be engaging through monitoring and evaluation, design and testing of new interventions or protocols, and voluntary outreach programmes – those more strongly associated with primary health and community partners. Those who do report post-graduates as an output of interaction were more likely to engage through (also) monitoring and evaluation, contracts, customised training, (also) design and testing of new interventions, and research consultancy. This combination of relationships was more strongly associated with the government, knowledge and firm partners of Cluster 3 (Figure 7.3).

The overlap of types of relationship serves as a reminder that there is no one to one correspondence between a partner, a type of relationship and an output, but that we are aiming to reduce complexity and discern common, most frequent and/or niche patterns.

Outcomes and benefits and associated relationship types

To deepen this analysis, we go on to examine the outcomes and benefits of interaction. As might be expected from the pattern of outputs, the most frequent outcomes are to the benefit of scientists and their reputations: relevant research focus and new research projects (WAI = 3.12), training and skills development (3.12), scientific and institutional reputation (3.04) and theoretical and methodological development in a scientific field (2.96). General, not easily measurable benefits to external partners are also quite frequently reported: public awareness and advocacy (2.9), and improved quality of life for individuals and communities (2.8).

Figure 7.7: Correspondence analysis of relationship types and outcomes



Analysis of the correspondence between types of relationship and outcomes yields a map that reflects less dispersion. This could indicate that the outcomes and benefits produced by the diverse relationship types are more common across MRC scientists.

Beginning in the top quadrants along Dimension 2 but close to Dimension 1, the frequent relationship type of monitoring, evaluation and needs assessment (R11) and participatory research networks (R17) are strongly associated with participatory research processes (B15) and cross-disciplinary knowledge production to deal with multi-faceted social problems (B19). Public awareness and advocacy (B1), and improved quality of life (B11), are close in distance to R 11 and R17 and further away from the point of origin, but they are also associated with these relationships types, perhaps less commonly or on a smaller scale. This pattern of engaged science that deals with social/health problems points to the impact of the strategic initiatives that bring together scientists from across the units.

In the bottom quadrants along Dimension 1 and 2, the relationship types of research consultancy (R12), collaborative curriculum design (R3), technology transfer (R13), and design, prototyping and testing of new technologies are associated with regional development (B12) as an outcome and also, with firm productivity and competitiveness (B9) and novel uses of technology (B10), which are located further from the point of origin but still associated. This points to the existence of health-related technology and innovation becoming commercialised and generating new productive activity, possibly interaction driven or supported by the Technology and Innovation directorate. However, the association between relationship type and outcome that is least likely to occur is joint commercialisation (R18) and firm employment generation (B8) (bottom left hand quadrant).

The relationship types in the bottom right hand quadrant of continuing education or professional training (R4), customised training (R5) and contract research (R14) are likely to produce the outcomes of scientific and institutional reputation (B17), relevant research focus and new research projects (B16) and training and skills development (B6). In the same quadrant, but further away from Dimension 1, are the relationship types of expert testimony (R7), closely associated with the outcome of improved post-graduate teaching and learning (B2), while the related type of postgraduate education (R1) is associated with the outcome of theoretical and methodological development in a scientific field (B18). It is likely that these result from interaction with knowledge partners in universities and science councils, in South Africa or internationally.

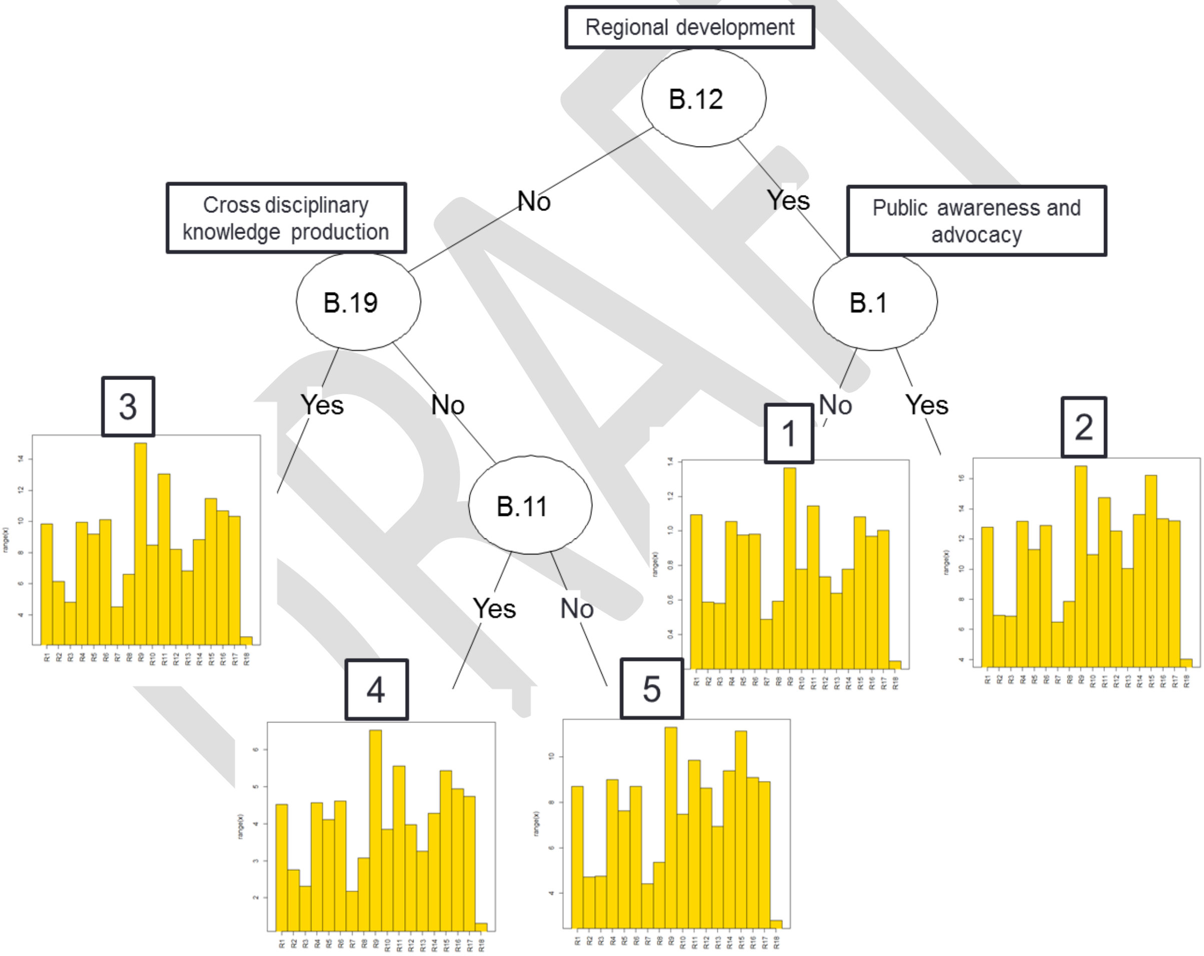
Policy research, analysis and advice (R6) relationships (top left hand quadrant) are strongly associated with the outcome of policy interventions (B4), and collaborative R&D projects (R15) with interventions plans and guidelines (B5).

The type of relationship important for primary health partners, that is, design and testing of new interventions or protocols (R9) is situated further from the point of origin and does not have a strong association with a specific benefit, although it seems to be associated with improved quality of life for individuals or communities (B11) or policy interventions (B4).

Community-based research projects (R16) are associated with community empowerment (B13), community-based campaigns (B3) and/or incorporation of indigenous knowledge (B14), but this is on a very small scale and represents the outcome of niche activity.

The diversity and concentration of interaction at MRC is best illuminated by a classification analysis of outcomes, which results in a tree with four splits, creating five groups of scientists with distinct patterns of interaction (Figure 7.8).

Figure 7.8: Classification tree of the splitting by partners on relationship types



The first major distinction is a split by the outcome of regional development (B12). Those who do contribute to regional development are then split by whether or not they contribute to public awareness and advocacy (B1). This is an outcome that is of indirect benefit, to a general public or stakeholders, rather than to a specific partner or community. Those who report that their interaction results in public advocacy (node 2) are more likely to engage in ways associated with the core of knowledge generation and innovation activity (Cluster 3 of types of relationship in Figure 7.4): through contract research, consultancy, M&E, technology transfer and collaborative R&D (in that order).

In contrast, those who do not report regional development are split by whether or not they contribute to cross-disciplinary knowledge production to deal with social problems (B19). This group is again split by whether or not their interaction leads to an improved quality of life (B11). These outcomes are both of direct benefit to specific stakeholders or communities, and represent a more engaged kind of science. Both groups of scientists represented in the two nodes on the left hand side (3 and 4) have similar profiles of most frequent types of relationship: monitoring and evaluation design and testing of new interventions or protocols and voluntary outreach programmes, while those who do report improved quality of life (node 4) also engage frequently through community-based research projects.

Those who do not report improved quality of life (B11) but do contribute to regional development and to cross-disciplinary problem solving (node 5), have a very similar profile of relationships to those who contribute to regional development and public awareness: contract research, consultancy, technology transfer, collaborative R&D and M&E (in that order).

Finally, a fifth group differs somewhat (node 1). Those who contribute to regional development only more frequently report types of relationship oriented to knowledge partners in universities and science councils: customised training, post-graduate education, collaborative curriculum design, M&E, and design and prototyping of new technologies.

Conclusion

In summary, it was not easy to discern a straightforward pattern of interaction at MRC. A wide spread of diverse clusters of interaction were identified, reflecting distinct organisational thrusts at key points, and the intellectual or financial drivers of individual units and scientists. While our analysis identified stronger and weaker associations between clusters of partners, types of relationship and outcomes, a specific partner or type of relationship could be associated in a number of ways.

Though a step-wise analysis to reduce complexity, it was possible to discern two broad orientations, with multiple variations and groups within these broad orientations.

One orientation was to interact with public and community health oriented partners, through a distinctive set of relationships to design community-based interventions based on assessment of needs, and with the outputs of new and improved protocols of direct benefit to communities, as well as the outcomes of cross-disciplinary knowledge production and improving the quality of life. This was evidence of growing interaction in line with MRC's social development mandate, to address the burden of disease, poverty and inequality. It reflected a more socially engaged science.

A second broad orientation was to knowledge generation and innovation oriented partners, through a wide range of relationships. Firms were partners on a small scale, grouped in a cluster of large and small firms and farmers and sectoral bodies. MNCs however, likely in the form of pharmaceutical companies, were associated with the main cluster of knowledge, government and funding partners. One distinct cluster of types of relationships was oriented to formal traditional research relationships, ranging from collaborative R&D, education and training, contracts and technology transfer. A second cluster of types of relationship was oriented more to applied research, in the form of consultancy and design and prototyping of new technologies. Joint commercialisation of new products represented a third, very small cluster. These types of relationship tended to lead primarily, but not only, to scientific publications and benefit scientific fields and reputations, addressing the mandate of scientific excellence. Outcomes were also likely to address the mandate of economic development and a generalised contribution to public awareness and advocacy around health issues.

This diverse pattern can be explained relative to the changing health paradigms at MRC, and to the state of organisational flux at the time of research.

Conclusion: science councils balancing multiple mandates

Introduction

The impetus for the research was the lack of an evidence base on the nature, scale and impact of interaction. The research thus aimed to explore the role of science councils in the national system of innovation, by empirically analysing their current patterns of interaction and networking with other actors:

- To investigate the nature and functioning of science councils' institutional policy, internal structure and support mechanisms that facilitate and constrain interaction with external social partners, particularly communities
- To map the extent and ways in which science councils extend their scholarship to promote innovation to the benefit of a range of external social partners, whether firms, public sector, communities or other social organisations

The research took place at a specific point in time, and presented an analysis of each science council with a lens facing backward to trace its historical trajectory, but focused very much on the conditions and practices of the present. Given that we are finalising the report in late 2014, more than a year after the initial fieldwork in early 2013, it was also possible to have a lens facing forward, showing how the councils evolved subsequently.

What is marked is how quickly change can occur, in conditions where there is strong leadership and a Board committed to driving a coherent strategy. Both the MRC and the ARC were organisations struggling to adapt to a new research paradigm that includes human development priorities as integral to scientific and technical knowledge production, and that includes communities and marginalised as partners and beneficiaries, alongside the more traditional knowledge partners, industry and government. Both organisations were fragmented, lacked strategic alignment and coherence around a shared vision, with pockets of excellence and institutional structures that were no longer fit the purpose for which they were originally created or for the new strategic policy. Both were in the midst of a process of ''revitalisation'' or ''turn-around''. The evidence suggests that a year and a half later, substantial progress was made to realise the intended changes. Our empirical data reflects the practice of scientists before, or at the same time as these changes were being made. This means that our analysis of their patterns of interaction and the institutional conditions that facilitated and constrained these patterns is likely already out of date and inaccurate – when applied to these specific science councils.

However, we would argue that the case studies are of value, by highlighting and illustrating the role of science councils in the national system of innovation, and by identifying conditions that facilitate, gaps, blockages and constraints to interaction. The analysis can thus speak to ways in which public research institutes can strengthen their interactive capabilities to realise shared national and organisational goals – the focus of the conclusion.

The role of science councils in the national system of innovation

Public research institutes were challenged to play more complex and more responsive roles in the national system of innovation in South Africa after 1994, to contribute knowledge and technology that will drive social and economic development. We noted that public research institutes in a late developing country like South Africa, with a complex colonial past, face the dual challenge of linking their national system of innovation to global knowledge flows and the frontiers of science, but at the same time, finding solutions to address context specific problems. Given the current challenges of inclusive development, we isolated three generic roles for science councils:

1. to enhance scientific excellence and participation in global knowledge and innovation networks
2. to create industry linkages that can promote economic growth and global competitiveness
3. to promote engagement that can contribute to a more equitable quality of life for all citizens

In the past, scientists would seek collaboration driven by intellectual imperatives, with other scientists in their disciplinary field who could provide missing or complementary insights and expertise to extend their work. In South Africa, this tended to be on a national basis, but could be international. Globally, public funding for research has decreased, driving organisations and scientists to seek funding from private sources, whether from firms, foundations or donors. These financial imperatives mean that the ability to interact and build networks become critical for science councils, in different ways from the past. Equally significantly, the new inclusive developmental policy imperatives now drive linkages and collaboration between scientists and external beneficiaries, who have largely been excluded from the benefits of science and technology in the past. The capability to promote and support interaction and partnerships thus becomes critical, and at the heart of science councils' research contribution to the national system of innovation.

Balancing and prioritising roles

We thus traced how each of the five science councils interpreted the three-fold policy mandate in relation to its core disciplinary fields and research paradigms, summarised in Table 9.1. Each was challenged to extend and shift its traditional scientific mandate, orientation and focus fields in distinct ways, in order to respond to the new national developmental demands and the reduced core public funding allocation. Science councils were challenged to develop their scientific reputation nationally and internationally, which required a shift for some, from maintaining national facilities and databases, and from largely applied research, to generate new knowledge and technology. South African science councils were more accustomed to addressing national problems distinct to context, and they were challenged to link more effectively to global issues and the knowledge and technology frontier. At the same time, the financial imperative to source a significant proportion of funding represented a challenge. Science councils that could offer research and development to tap into a sectoral value chain were at an advantage, in accessing private sector funding. The growth of research oriented to the public good, or to vulnerable and marginalised communities, requires the ability to access public sector or international donor funding. Those with established reputations were at an advantage to access funding from public-oriented foundations and donor agencies.

In chapters 4 to 8, we analysed how each science council grappled to balance the simultaneous demands of these financial, intellectual and developmental drivers, in distinct ways over time. All succeeded in articulating new and ambitious institutional and strategic policies, which gave priority to unique combinations of the three roles. However, it is evident that science councils have grappled to varying degrees, to reorient their scientists and to create an organisational structure and mechanisms to give effect to these strategic policies.

Table 9.1: Comparing mandates of the science councils 2012/13

	CSIR	MRC	ARC	Mintek	CGS
Type of PRI	Perform research basic and applied research, across a number of scientific and technology fields	Mission oriented: perform and fund	Mission oriented: perform Agency mandate: Repositories and collections	Mission oriented: perform	Mission oriented: perform Agency mandate: Repositories and collections
Traditional mandate	Multi-disciplinary research and technological innovation, to foster industrial and scientific development in the national interest	Medical model: causes and treatment of disease	Commodity oriented: Serve the needs of commercial farmers Primary and agency mandate	Maximize the value derived from mineral resources	Geological survey for government and public Fixed and variable mandates
Current three fold mandate	1. Cutting edge science and growing new generation of scientists 2. Advanced high technology manufacturing, to strengthen the industrial base and to grow new competitive niche sectors 3. Improvement of quality of life of the people	1. Research, development and technology transfer to promote improvement of health and quality of life 2. Relevant and responsive research translation	1. Conduct research and develop technology 2. Contribute to a better quality of life by alleviating poverty and ensuring natural resource conservation 3. Transfer technology that promotes agriculture and industry	1. Research and develop efficient mineral processing technologies and value added products and services 2. Promote the mineral-based economies of rural and marginalized communities	1. Basic geoscience research to contribute to national and international science 2. Maintain national facilities / repositories 3. Knowledge services to commercial clients 4. Knowledge services to government, in relation to geohazards in the public interest

				3. Build world-class R&D excellence	
Main challenge to shift traditional mandate after 1994	Focus on impact of R&D and technology transfer Strengthen scientific reputation	Shift to health paradigm that responds to main causes of ill-health Scientific reputation	Expanded mandate: smallholder and new farmers Develop scientific reputation	Expanded mandate: small scale miners Strengthen scientific reputation	Expanded mandate: respond to geohazards Develop scientific reputation
Funding challenge	Funding drives research agenda	Balance of funding to intra and inter mural units	Smallholder farmer mandate and repositories/ collections require public funding	Research for stakeholders vs public good	Core mandate as geological survey requires sustained public funding
Parliamentary grant	30%		68%	30% Aim to shift to 50% for sustainability	30%

Patterns of interaction

The core of the research was a methodology to discern the scale and nature of interaction in the practice of individual scientists across each science council. This is an extremely complex task, given the multiple combinations of drivers possible - a mix of old and new national and organisational imperatives, and individual motivations. Moreover, an individual scientist could be involved in multiple projects and interactions of different kinds. Our approach was thus to identify the main pattern and trends as well as niche areas of activity. Each chapter analysed the pattern of interaction at one science council relative to its mandate and organisational arrangements. Here, we compare across the four science councils for which we have reliable survey data.

The scale of interaction and networks

Table 9.2 begins by comparing the scale of interaction, which reflects a growing awareness on the part of scientists, of the potential partners, users and socio-economic impact of their research. On average, almost a fifth of scientists, 19%, reported that they do not extend their knowledge to the benefit of external social partners (Table 9.2). This is exactly the same proportion of academics in five universities, who reported that they do not interact, in a similar survey conducted in 2011 (Kruss et al 2012).

Table 9. 2: Comparing the scale of interaction

	Population of scientists	Sample of scientists	Scientists do not interact	Average partners
ARC	501	383	17%	8.7
CGS	157	117	11%	7.7
Mintek	214	179	27%	6.9
MRC	451	283	21%	9.2
Average			19%	8.1

For the most part, these scientists do not interact because it is not seen as part of their role and identity as scientists, and because of a lack of organisational support and prioritisation. A higher proportion of scientists at Mintek reported that they do not engage directly with external partners – although we showed that this is likely because they provide services to other internal units that may have direct linkages with external partners. Very few scientists at CGS reported that they do not interact, but we showed that this is largely because of the services offered as a national facility and repository. A fifth of scientists at MRC do not interact, and we showed that this is more likely because they are driven by traditional intellectual imperatives.

In contrast to the universities, these scientists tend to work with a high average number of partners, and many interact through networks. Networks are most likely to be of benefit to the national system of innovation, as they can be to the benefit to each partner, and are more likely to involve knowledge exchange in various forms, contributed by each partner depending on their expertise and role.

Four distinct patterns

In this section, we summarise the distinct patterns at each science council as a baseline for the discussion that follows.

Interaction at Mintek is predominantly with firms, taking the forms of contracts, consultancy, needs assessments and technology transfer, for new or improved processes and products, but seen to enhance scientific reputations. There is a significant scale of interaction with other knowledge users that tend to take more collaborative forms and lead to traditional academic outputs and reputations. A niche of downstream, beneficiation-oriented research and development related to health applications of minerals is highlighted. A small emergent niche of activities addresses imperatives to support small scale miners and communities to promote livelihoods and economic development. There is also evidence of a small set of philanthropically oriented activities with communities, taking the form of corporate social responsibility activities, related largely to a role in education and skills development.

There are two distinct clusters of interaction at CGS. The strongest trend is aligned with the traditional mandate as a geological survey. Interaction is with a cluster of African and national government, firm and knowledge partners, and typically takes the form of research consultancy, contracts and collaboration, as well as in relation to post-graduate education, training and skills development. The outputs are most likely to be reports and scientific collaboration, and to a lesser extent, academic outputs. The outcomes of interaction are primarily perceived to enhance scientific reputation, but there is a group of scientists that focus primarily on training rather than scientific reputation, for whom the contribution to knowledge generation is clearly not as significant. A second smaller cluster of interaction responds to government social development imperatives. Interaction is with communities, NGOs, and other civil society actors, in various forms of policy, monitoring collaborative and participatory research relationships, to address a wide range of geohazard and environmental problems. Significantly, this pattern of interaction does yield benefit to scientific reputation for small groups of scientists, and can inform policy interventions and the incorporation of indigenous knowledge.

The pattern of interaction at ARC reflects organisational attempts to respond to the needs of both commerical and resource poor farmers. Most scientists are actively engaged, in networks of multiple partners, to conduct strategic and applied research, and technology transfer and diffusion. The most frequent cluster of interaction – and clearly, still the most highly valued within the organisation - promotes the 'traditional mandate' of responding to the needs of commercial farmers to enhance global competitiveness, and particularly, to improve (global) scientific excellence and reputation. The outputs and outcomes in regard to scientific excellence are the most frequently reported. A second significant cluster of interaction promotes the 'extended mandate' of responding to the needs of small and resource poor farmers, stimulated and supported by government and funding agency development priorities. Small clusters of emergent activity respond to the needs of impoverished communities, but with a limited scale of outputs and outcomes as yet.

A spread of diverse clusters of interaction was identified at MRC, but two broad orientations were discerned, with multiple variations and groups within these broad orientations.

One was to interaction with public and community health oriented partners, through a distinctive set of relationships to design community-based interventions based on assessment of needs, and with the outputs of new and improved protocols of direct benefit to communities, as well as the outcomes of cross-disciplinary knowledge production and improving the quality of life. This was evidence of growing interaction in line with MRC's social development mandate, to address the burden of disease, poverty and inequality, reflecting a more socially engaged science.

A second broad orientation was to knowledge generation and innovation oriented partners, through a wide range of relationships. Firms were partners on a small scale, grouped in a cluster of large and small firms and farmers and sectoral bodies. MNCs however, likely in the form of pharmaceutical companies, were associated with the main cluster of knowledge, government and funding partners. One distinct cluster of types of relationships was oriented to formal traditional research relationships, ranging from collaborative R&D, education and training, contracts and technology transfer. A second cluster of types of relationship was oriented more to applied research, in the form of consultancy and design and prototyping of new technologies. Joint commercialisation of new products represented a third, very small cluster. These types of relationship tended to lead primarily, but not only, to scientific publications and benefit scientific fields and reputations, addressing the mandate of scientific excellence. Outcomes were also likely to address the mandate of economic development and a generalised contribution to public awareness and advocacy around health issues.

Forms of interaction, outcomes and benefit

The strongest trend across the board is interaction with knowledge partners, which may take a number of forms. They can be traditional, focused on building future scientific capacity. They can also be new forms of partnerships with government and/or formal sector firms, who may be the actors commissioning and funding research contracts, consultancies and collaborations. They can be partnerships with firm partners that involve knowledge exchange and direct interaction, both in the formal sector and increasingly, in the informal sector with small scale farmers, miners, cooperatives and micro-enterprises. These partnerships are primarily to the benefit of the science council's reputation but also to the immediate client or stakeholder. Although there may be no direct interaction and knowledge exchange with beneficiaries, such research collaborations may be to the benefit of the public and citizenry in general, such as work on geo-hazards, water quality or health solutions, and may have significant impact on the quality of life.

Small potentially significant clusters of direct interactive activity with vulnerable communities and informal sector enterprises at the local level are emerging in each science council. These occur on a smaller scale than the main patterns of interaction with knowledge, government and industry partners. They require technology transfer and direct knowledge exchange, and challenge the traditional ways in which scientists have worked. They may involve local and regional government partners, or even large firm partners. We have seen how this activity tends to be based in specific dedicated external interface units, such as a small business promotion unit, or in research units that are committed to extend their work to wider social benefit. There is some evidence of such direct forms of interaction taking philanthropic forms, but more prevalent, of scientists trying to find new ways to work at the local level in participatory networks. This may require the involvement of civil society and development partners that have missing expertise and capabilities to work with marginalised communities, as well as organisational support and recognition.

Implications for policy and organisational practice

The need to enhance scientific excellence

The pressure to link the national system of innovation to global science is increasing. Science councils have tended to produce primarily applied research, for which outputs are client reports and popular publications for users. The drive to enhance scientific excellence is incentivised in the performance criteria of each science council. Table 9.4 illustrates the average growth in publications, 26% over the past five years. Note that science councils tend to calculate the total number of scientific publications to include journal articles, conference presentations and reports. The WAI for outputs showed that for CGS, ARC and Mintek, the most frequent output was reports and other non-academic publications. Only at MRC were academic publications the most frequent. The data thus needs to be read with this trend foregrounded.

MRC had produced the highest number of publications in the past, and the drop in the 2013/14 year can be attributed to a period of organisational turbulence, rather than a significant decline, as they still reported the highest number of publications per scientist. ARC and Mintek had the highest growth, but off the smallest bases, from less than 0.3 publications per scientist in 2008/9, to 0.6 in 2013/14.

Table 9.4: Number of publications per science council 2013/2014

Science Council	No. of Scientists 2013/2014	No. Scientific Publications 2008/2009	No. of scientific Publications 2013/2014	% increase	Publications per scientist[12] 2013/2014
ARC	501	144	302	52%	0.6
CGS	157	109	145	25%	0.9
CSIR	711	343	477	28%	0.5
MINTEK	214	56[13]	128	56%	0.6
MRC	451	653	451	(31%)	1
Total	2 034	1 305	1503		
Average				26%	0.7

Source: compiled from Annual Reports 2013/14

[12] Calculated roughly by dividing the total number of publications per year by the number of scientists per year.
[13] This data is for the 2012 year, as the only data available.

Comparison of the WAI for knowledge partners only showed that most frequent interaction was with local universities (3.2), while interaction with international counterparts were not commonly reported (average WAIs below 2.5). Mintek scientists seem to have the most active collaboration with knowledge partners, reporting the most frequent interaction with national and international science councils, and international universities. ARC reported the most frequent interaction with universities, and we showed how this was influenced by the small national base of agricultural research expertise concentrated in a few university departments.

Table 9.5: Comparing WAI for knowledge partners across science councils

	National universities	**National science councils**	**International universities**	**International science councils**
ARC	3.35	2.71	2.34	2.02
CGS	3.21	2.84	2.30	2.23
MINTEK	3.17	3.08	2.63	2.53
MRC	3.05	2.70	2.51	2.17
Average	3.2	2.83	2.45	2.24

The degree of collaboration between national science councils was relatively low, pointing to a potential blockage or misalignment. We have shown how Mintek and CSIR conduct health related research for example, or how CGS and Mintek's work can address different aspects of the same problem in the exploratory or close down phases of mines, and so on. Alignment of research from distinct disciplinary traditions in a complementary manner, to address complex social and economic problems more strategically is critical, particularly in the context of scarce resources.

In sum, the evidence suggests the need for continual prioritisation of the scientific excellence role, in order to link to global science, and to enhance national multi-disciplinary collaboration, in order to contribute to the knowledge base of the national system of innovation.

Organisational conditions that can promote and support interaction

The organisational conditions that promote and support interaction are for the most part, tacit. Only recently have the science councils realised their strategic significance, and begun to put in place more structured initiatives at the organisational level. These capabilities are important if science councils are to be active agents within the national system of innovation, maintaining their scientific autonomy, and not simply responding to or complying with, government policy directives or market demand.

Table 9.6 compares and summarises the organisational conditions found in each science council, providing a snapshot of the structures and mechanisms to support and promote interaction and the realisation of organisational mandates.

None of the science councils have the equivalent of a formal engagement policy in the way that universities do. However, the mandate and organisational objectives do all spell out the commitment to partnerships and linkages with clients and stakeholders, and serving national development objectives, in a far more direct way than universities. The commitment to engagement is thus largely tacit, being integral to their applied and strategic research mandate.

Internal alignment and coordination across programmes and units to address these strategic organisational mandates is a challenge for most of the science councils. Varying degrees of fragmentation and a lack of internal coherence and coordination between units was observed. Most successful is a formal matrix structure based on a formal administrative system to underpin internal collaboration at Mintek. The other science councils have recognised the value of such a structure, and aspire to create such a system in future. CSIR, ARC and MRC now have dedicated high level executives and programmes to drive and coordinate multi-disciplinary, cross-unit ''strategic initiatives'', but it is not clear how wide and how deep their reach is within the organisation as yet. For the most part, units work in silos and may even compete internally for their slice of the limited funding pie. The decision to interact directly with external partners or not, is taken largely by the individual scientist, or the head of a unit.

Most science councils have external interface mechanisms that promote contracts with knowledge partners. These often take the form of a formal memorandum of understanding, related to staff exchange and post-graduate education. They have external interface mechanisms for technology transfer, commercialisation and IP sharing, with industry partners, in the form of a technology transfer division. Facilities such as repositories, regional offices and sale of products are important external interface mechanisms for clients and the general public.

A new trend is a high level manager responsible for cross-cutting strategic projects to address complex national problems related to the quality of life, drawing in multi-disciplinary expertise and co-ordinating contributions from across the organisation as well as recruiting external partners.

External interface structures to interact with small-scale economic agents marginalised communities and related partners are not as well developed. They are often the preserve of a specific programme or unit that works across the organisation with varying degrees of success, such as a small business development unit, or training and extension strategy.

Incentive mechanisms are present in the form of performance monitoring systems that variously include criteria to promote interaction, primarily with universities and firms, but also small-scale informal producers and communities. Most scientists are driven by individual interpretations of intellectual, financial and developmental imperatives to pursue interaction, for intrinsic rather than extrinsic reward.

Table 9.6: Organisational conditions that facilitate and constrain

	CSIR	MRC	ARC	Mintek	CGS
Internal interface structures	Large and complex: Operating Business Units and Research Centres Challenge of coordination Research Impact Areas, Flagships and Strategic initiatives to coordinate multi-disciplinary collaboration Stakeholder Alliances and Communication unit: partners and clients	Unstructured, fragmented, silos, incoherent IP office Contracts system Strategic research initiatives BUT recently reorganised into 8 health-problem oriented over-arching programmes Individual scientist and unit driven	R&D and the Technology Transfer segments intended to complement one another Fragmented, incoherence: dispersed widely geographically, diverse disciplinary niches, long established identities of research institutes, reflecting national, regional, agricultural or environmental problems and priorities BUT recently reorganised into 2 commodity and 2 stakeholder oriented over-arching programmes	Matrix structure supported by a formal administrative system (centralized project collaboration register) Technology segment (commercial business) Research and Development segment Business Development (marketing, support services to all business units) Clusters: multi-disciplinary teams from various units led by a team leader who interacts with Line Managers across the strategic divisions Coordinators to support internal interaction and	Fragmented, dispersed geographically across 6 provinces, incoherent: high degree of unit autonomy Strategic Planning Unit: operational coordination and planning Internal collaboration largely ad hoc unstructured, based on individual relationships Model of a matrix organisation an aspiration (pilot process)

				deepen communication at operational levels Rotation of Line Managers to familiarise with all aspects of the organisation	
External interface structures	Strategic initiatives to coordinate multi-disciplinary problem solving Strategic Partnership unit: insertion as strategic organistional priority : hosting of consultative forums, priority at executive levels of decision-making Promotion of partnerships with universities and other research organisations driven centrally Formal memoranda of agreement Licensing and Ventures unit: technology transfer and commercialisation functions	Strategic health innovation programmes National Collaboration Research programmes led by senior managers Technology Transfer Office Innovation Centre Health Related Platforms Research translation initiatives	Technology transfer segment: Training unit (extension services, training strategy across units) Commercialisation (technology packaging) Business Generation Sale of ARC products (resources, fresh produce, manufactured goods, documentation Smallholder Development Programme	Business Development Unit Small-Scale Mining Business unit as main entry point for small-scale miners and subsistence miners, focused on developmental activities Technology Transfer Office Exhibitions Advertisements of products, Sales of services and products Website	Business development Intellectual property interface structures absent Large-scale scientific networks based on formal Memoranda of Understanding signed at corporate level Regional offices Museum, library, sale of maps: core facility, and repository

	International research alliances Research Centres highly visible				
Incentive mechanisms	Corporate objectives part of shareholder compact, translated into performance indicators KPAs more likely to drive publication and contribution to scientific mandate System of career ladders "Freedom to pursue one's research"	Corporate objectives part of shareholder compact, translated into performance indicators Targets to improve quality, reputation "Freedom to pursue one's research"	Corporate objectives part of shareholder compact, translated into performance indicators Targets prioritise scientific quality and reputation, interaction oriented to global competitiveness mandate more strongly Share of profits to encourage commercialisation "Freedom to pursue one's research"	State grant allocation is adjusted according to how effective and productive each unit is within a cluster Corporate objectives part of shareholder compact, translated into performance indicators Output indicators: scientific indicators (conferences, articles, reports); technology related (patents, technology transfers, prototypes, units of plant and equipment, value of control system sales, value of Certified Reference Material sales);	Corporate objectives part of shareholder compact, translated into balanced score card system Targets and reward to improve quality, reputation "Freedom to pursue one's research"

				indicators of social involvement *(*Customer Satisfaction Rating Index, new businesses created, people trained) "Freedom to pursue one's research"	

We thus argue that to achieve their three-fold mandate in a more strategic manner, there are a number of aspects that can be changed that are within the power of science council leadership and management. These require enhancing their internal capabilities at a number of levels:

1. Strengthening internal coordination and alignment between individual business units, and with organizational goals
2. Prioritising – and giving organizational authority to - structures and mechanisms that support scientists to extend their research outward, and to link potential external partners and beneficiaries into their knowledge and technology opportunities
3. Incentives for individuals and units that will promote their will to engage and to align with organizational mandates in a more balanced manner

Systemic conditions that facilitate and constrain

However, conditions in the national system of innovation may facilitate or constrain interaction and the effective role of science councils. Abstracting across the five science councils, we identify potential blockages, gaps, and facilitators that became evident at the macro-level, within the national system of innovation. These may constrain science councils from achieving their mandates, despite their best organisational efforts.

Funding has been a major blockage to realising goals and mandates, for some science councils. With a decline in core parliamentary grants to around 30%, financial imperatives have driven scientists to draw on their reputations to seek funding from other sources, whether donors, clients or other stakeholders. This leads to the risk of 'funder' and individual driven research agendas, which potentially leads to organisational incoherence and misalignment withstrategic goals. It can also constrain applied research to develop solutions in the public interest, or block the use of funds to maintain infrastructure and equipment, which in turn, can impact on long term scientific production.

A distinctive role of science councils in the NSI is the maintenance of national collections and repositories, the agency mandate of CGS and ARC being two key instances. These collections require dedicated funding streams and consistency over long periods of time. The risk to the NSI of inadequate funding is substantial, as these repositories are used for regulatory and safety purposes. Moreover, they can function as very effective external interface mechanisms, providing crucial services to firms, farmers, local government, communities and individuals.

The issue of continuity of funding is important across the board, however. The rapid changes in organisational fortunes are often in response to either a lack of funding, or to new funding sources, which could often be short term, shaped by new priorities of a government department. This creates a risk for promising scientific work that may require longer periods to mature. One science council had thus decided to shift its percentage of state funding to 50% of the total expenditure, as a more sustainable balance over time that could ensure a higher degree of consistency.

The imperative to commercialise and exploit knowledge and technology is a potential constraint for some science councils. For example, CGS offers knowledge services that are required in pre- and post-competitive segments of the value chain, which do not lend themselves to generate revenue. Likewise, MRC research is oriented primarily to the health interests of the public. Prioritisation of commercialisation and exploitation of IP can diffuse scientists' energy and focus, with no guaranteed financial benefit. A new focus on technology transfer and commercialisation at MRC has shown that it is possible to generate revenue that can then be used in various ways to achieve other developmental or scientific goals, however. Given the new IP Act this is an area that requires careful consideration and more evidence.

Another potential blockage is the capabilities of the line department to lead and focus research agendas, in alignment with DST. In some cases, SETI Reviews have noted that the lead department lacks capacity, and recommended that the science council should be moved directly under the control of DST for more effective coordination. A counter argument arises from cases where there is a close working relationship between the lead department and the science council, and alignment with sectoral policy frameworks, such as that which traditionally existed between ARC and DAFF, and now with DLRRD in relation to small farmers. The role of the Board and alignment between the DST and the lead department is thus a critical area for future coordination and strengthening.

What is also notable over time is a sense of ''mission overload'', with the expectation that science councils will be responsive to multiple policy initiatives, some of which may be potentially contradictory, particularly in organisations with limited financial and human resources. Thus, our analysis of annual reports shows shifts in the discourse and language used by the science councils, changing frequently as government policy goals and priorities shift. There is evidence of a constant ''adding on'' of requirements, to respond to new national policy frameworks such as the government outcomes system, and development plans such as the NDP, as well as to innovation policy frameworks developed by DST, as well as to sectoral policy frameworks in health or mining or agriculture. The impact of unrealistic or over-burdened expectations on leadership and individual scientists is a potential risk for the national system of innovation.

A positive facilitator of progress to actualise the complex mandate is the periodic SETI Reviews. External and internal review and self-reflection have become part of the organisational culture of the science councils, and this facilitates change and adaptations to foster alignment with strategic goals. These reviews should be available in the public domain in order to facilitate accountability.

In conclusion