CREATING **KNOWLEDGE** NETWORKS

WORKING PARTNERSHIPS IN HIGHER EDUCATION, INDUSTRY AND INNOVATION

CREATING **KNOWLEDGE** NETWORKS

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HSRC PRESS

Compiled within the Education, Science and Skills Development Research Programme of the Human Sciences Research Council
Published by HSRC Press
Private Bag X9182, Cape Town, 8000, South Africa
www.hsrcpress.ac.za

First published 2006

ISBN 0-7969-2132-6

Copy editing by Biddy Greene
Typeset by Jenny Wheeldon
Cover design by Nazley Samsodien
Print management by comPress

Distributed in Africa by Blue Weaver
PO Box 30370, Tokai, Cape Town, 7966, South Africa
Tel: +27 (0) 21 701 4477
Fax: +27 (0) 21 701 7302
email: orders@blueweaver.co.za
www.oneworldbooks.com

Distributed in Europe and the United Kingdom by Eurospan Distribution Services (EDS)
3 Henrietta Street, Covent Garden, London, WC2E 8LU, United Kingdom
Tel: +44 (0) 20 7240 0856
Fax: +44 (0) 20 7379 0609
email: orders@edspubs.co.uk
www.eurospanonline.com

Distributed in North America by Independent Publishers Group (IPG)
Order Department, 814 North Franklin Street, Chicago, IL 60610, USA
Call toll-free: (800) 888 4741
All other enquiries: +1 (312) 337 0747
Fax: +1 (312) 337 5985
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PREFACE

A vision of the ideal role of research partnerships between higher education and industry in a rapidly globalising knowledge economy is becoming increasingly prevalent. However, there is a great deal of dissonance between this vision and the realities of research, innovation and development in the South African context, which is characterised by fragmentation, inequalities and uneven capacity.

In its research programme on human resource development, the Human Sciences Research Council has undertaken a project designed to explore the extent to which the networked practices that are believed to characterise the knowledge economy have indeed begun to penetrate South African higher education and industry. Where networks and partnerships have developed, how have they taken shape in the South African context – within specific national policy and economic imperatives? To what extent is there evidence of collaboration in knowledge generation, diffusion and application that will ultimately contribute to innovation? In what ways has government succeeded in promoting such partnerships? What are the kinds of changes and benefits that partnerships are bringing about in both higher education and industry?

Three high technology bands have been identified as priorities for developing a national system of innovation that will improve South Africa's international competitiveness and economic development. The relatively new high technology fields of information and communication technology (ICT), biotechnology, and new materials development have been identified as those most likely to generate benefits for South Africa. They were therefore selected as the empirical focus for this study. Understanding the conceptions and practices of research partnerships in each of these three fields will inform our understanding of, and responsiveness to, high technology needs and innovations in South Africa.

This large-scale, empirical study is of necessity primarily an exploratory one, aiming to open up the field and lay down benchmark descriptions of the partnership and network activity emerging in South African higher education and industry. It does so through a series of audits and mapping exercises and a set of in-depth case studies.

The study was conceptualised in terms of four distinct but closely interrelated sub-studies or components. Components Two to Four are available as separate publications in the series *Working Partnerships: Higher Education, Industry and Innovation.*

Component One was largely conceptual. It provided an entry point into the conceptual and comparative literature on higher education–industry partnerships, as well as being an introduction to the 'state of the art' in each of the three high technology fields in South Africa, thus laying a foundation for the entire study.

Component Two aimed to illuminate government's role in promoting research partnerships by exploring the forms of government contribution through THRIP and the Innovation Fund, and the extent and nature of resultant partnerships. Data was gathered on industry and higher education beneficiaries, on the nature of co-operation at project level, and on selected measures of the outputs of the co-operation. The 2003 monograph, *Government incentivisation of higher education–industry partnerships in South Africa*, showed how partnerships, networks and innovation are developing amongst beneficiaries of government-incentivised funding in general, and in the three high technology fields in particular.

Component Three aimed to map partnerships across the higher education landscape, to investigate the scale and form of research linkages and collaborative practices between higher education institutions and industry in each of the three fields. Given the uneven capacity of higher education institutions and their different historical legacies, and given the different modes of operation of different knowledge fields, this component explores the ways in which partnerships develop and take specific forms in distinct institutional and knowledge contexts. A book on this component titled *Working Partnerships in Higher Education, Industry and Innovation: Financial or Intellectual Imperatives* was published in 2005.

Component Four, the present monograph, focuses on the demand side at enterprise level, and on industrial sectors related to the three high technology fields. In a limited set of cases, we explore in depth the dynamics of South African forms of networks, to unpack their multi-linear, contingent and tacit dimensions. We also consider their impact on knowledge production and technological innovation. The book cited above and this monograph in particular, are companion pieces, and complement one another.

ACKNOWLEDGMENTS

This study would not have been possible without the willingness of the industry, higher education and other partners involved in each of the eleven cases to open their research enterprise, organisation and function to scrutiny. We hope that this monograph indicates that their trust was well-placed, and that insights from their experience will be of wide relevance and significance to researchers across the higher education system in South Africa.

A dedicated and incisive team of researchers conducted the case studies, without which the report would not be possible. In alphabetical order, we thank, for their excellent powers of observation and analysis: Michael Cosser, Carel Garisch, Candice Harrison, Gilton Klerck, Susan Meyer, Rachmat Omar, Lesley Powell and Vanessa Taylor.

A team of authors produced this report, and they have benefited from the critical guidance and support of a reference group, which included the researchers listed above. Prof. Eddie Webster and Dr Andre Kraak are the other key members of the team; they influenced the conceptualisation and design of the study, and assisted with the emerging analysis presented in this monograph. Gilton Klerck produced a review of the literature that informed the empirical research. Their intellectual contribution to the project is gratefully acknowledged.

Finally, the study would not have been possible without the generous support of the Carnegie Corporation of New York, particularly in the persons of Courtenay Sprague and Narciso Matos.

ABBREVIATIONS AND ACRONYMS

AMF	arbuscular mycorrhizal fungi/fungal
AMTS	Advanced Manufacturing Technology Strategy
ARC	Agricultural Research Council
BRIC	Biotechnology Regional Innovation Centre
CAMA	Contemporary African Music and Arts Archive
CAVES	Collaborative African Virtual Environment System
CCSG	Computer and Control Systems Group
CHE	Council for Higher Education
Chemin	South African Chemical Technology Incubator
CoE	Centre of Excellence
COHORT	Committee of Heads of Research and Technology
COMPS	Centre of Material and Process Synthesis
CRU	Catalysis Research Unit
CSA	Chicory South Africa
CSIR	Council for Scientific and Industrial Research
CU	Catholic University of Leuven
CVCL	Collaborative Visual Computing Laboratory
DACST	Department of Arts, Culture, Science and Technology
DIT	Durban Institute of Technology
DNA	deoxyribonucleic acid
DoE	Department of Education
DoL	Department of Labour
DST	Department of Science and Technology
DTI	Department of Trade and Industry
DWAF	Department of Water Affairs and Forestry
EBI	European Bioinformatics Institute
ESL	Electronic Systems Laboratory
FABI	Forestry and Agricultural Biotechnology Institute
FSA	Forestry South Africa
F'Satie	French South African Technical Institute in Electronics
FSO	Free-space optics (also termed free-space phototronics)
GDP	Gross Domestic Product
GSM	global system for mobile computing
HESA	Higher Education South Africa
HSRC	Human Sciences Research Council
IAM	Institute of Applied Materials
ICFR	Institute for Commercial Forestry Research
ICT	information and communication technology/ies

Incentif	Incubation Centre for Technological Innovation
ISP	internet service provider
IPS	Institute of Polymer Science
Isett	Information Systems Electronics and Telecommunication Technologies
ISCW	Institute for Soil, Climate and Water
IT	information technology
JSE	Johannesburg Stock Exchange
MCC	Magnesium Compound Consortium
MOU	memorandum of understanding
MUD	multi-user domain
MSMI	Multi-Sensor Microsatellite Imager
NACI	National Advisory Committee on Innovation
NASA	National Aeronautics and Space Administration
NCTC	Natal Co-operative Timber Company
NMD	new materials development
NRF	National Research Foundation
OVD	outside vapour deposition
PETCRU	Port Elizabeth Technikon Catalysis Research Unit
PGM	platinum group metals
PMD	polarisation mode dispersion
PRG	Pollution Research Group, University of Natal, Durban (Chapter 2) and Process Research Group, University of the Witwatersrand (Chapter 4)
R&D	research and development
RNA	ribonucleic acid
SANBI	South African National Bioinformatics Institute
SARIMA	Southern African Research and Innovation Management Association
SDSC	San Diego Supercomputer Center
SETA	Sectoral Education and Training Authority
SME	Small and Medium Enterprise
SMME	Small, Micro and Medium Enterprise
THRIP	Technology and Human Resources for Industry Programme
TIPTOP	Technology Innovation Promotion through the Transfer of People
TNO	Nederlanse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek
TPCP	Tree Protection Co-operative Programme
UCT	University of Cape Town
UPE	University of Port Elizabeth
US	University of Stellenbosch
UWC	University of the Western Cape

VAD	vapour axial deposition
VANS	Value-Added Network Service
VE	virtual environment
VIS	Visual Information Systems
VOIP	voice-over internet protocol
VSAT	very small aperture technology
WMTG	Water and Membrane Technology Group
WRC	Water Research Commission
WTSI	Wellcome Trust/Sanger Institute
Y2K	Year 2000 problem/millennium bug

CHAPTER 1

Higher education and contemporary challenges: investigating industry partnerships and networks

Glenda Kruss

Over the past decade, higher education institutions in South Africa have been increasingly under pressure to become more responsive to economic and social development needs, in the context of a new global imperative towards a 'knowledge economy'. New organisational forms, manifested in strategic research networks of higher education, industry and science council partners, are emerging worldwide around the ability to generate, process and apply knowledge. In the South African context, there is pressure to engage in research that is more 'relevant', applied and strategic, in partnership with industry or science councils. A growing emphasis within science and technology is to enhance 'research utilisation' and improve mechanisms of 'technology transfer' to industry, the public sector or impoverished communities. The challenges thus raised for academics, research managers, institutional leaders and policy-makers are multi-faceted and intense.

This monograph aims to contribute to informing the ways in which higher education engages with contemporary challenges, by showing how knowledge networks are being created in a new global and national context. Essentially, it will describe the 'cutting edge' of current research partnerships between higher education and industry, which are emerging in high technology fields in South Africa.

Castells's interpretation of global shifts

The new pressures on higher education may be interpreted in the light of major organisational changes initiated by global economic, social and political shifts, in what Castells (1996) has termed the 'age of informationalism'. Essentially, Castells analyses the development of:

> …different organisational trajectories, namely specific arrangements of means oriented towards increasing productivity and competitiveness in the new technological paradigm and in the new global economy. (1996: 153)

A range of organisational trajectories or trends may be analysed, interacting and taking different forms in specific national contexts, such as in South Africa. However, Castells argues that they all arise out of a process of disintegration of the organisational forms of industrial capitalism, and of the model of a vertical, 'rational' bureaucracy. The model used hitherto, of the large, vertical corporation, operating under conditions of standard mass production, and involving control of markets by a small number of competitive firms, is in crisis.

To be competitive today, organisations need flexible production methods that rely extensively on information. Globalisation has redefined the basis of competition between firms, which now relates to quality and scope, and to the most effective and efficient design configuration for producing a commodity. This means that the ability to reconfigure and customise in response to changing market conditions has become paramount. Such flexibility requires high level skill competences that a single firm may not have, forcing collaboration with others, to extend the boundaries of knowledge in new design configurations.

New organisational forms are required in the age of informationalism. Castells provides evidence to demonstrate that although they may take a range of forms and cultural expressions, they are all based in networks. The new organisational changes – such as webs of strategic alliances, networks, sub-contracting agreements and decentralised decision-making – are enhanced by new information technologies, leading to a complex process of interaction and convergence between organisational requirements and technological change.

Under these new global economic conditions, Castells proposes, networking becomes the fundamental form of competitive strategy – embodied in the form of the 'network enterprise', which he defines as:

> The specific form of enterprise whose system of means is constituted by the intersection of segments of autonomous systems of goals. (1996: 171)

The component parts of the network are simultaneously autonomous and dependent on the network, and may also be part of other networks, as well as aimed, at the same time, at other goals. A network's performance will depend on its 'connectedness', a structure to enable communication between its component parts, and on its 'consistency', a sharing of interests between the network's goals and the goals of its component parts.

In short, the network enterprise is the new organisational form of the informational economy precisely because it is able to generate knowledge and process information efficiently, to be adaptable and flexible as goals change in the context of rapid economic, cultural and technological change, and to innovate – a key new competitive weapon. And in turn, this collaboration changes the nature of knowledge generation and scientific discovery, based on a decrease in the divide between science and technology, trans-disciplinary knowledge production, and an increase in knowledge and technology generation partnerships.

The network as policy ideal?

A sociological analysis of the 'network society' such as that proposed by Castells has come to operate in two ways – as a useful conceptual device for analysing the changes taking place globally in a range of national contexts, but also as a normative set of 'ideals' towards which specific nation states aspire. The concepts of the triple helix (described below) and the entrepeneurial university were developed to explain the changing nature and relationships of higher education under new global conditions. Viale and Etkowitz (2005: 21) argue these concepts are, 'often viewed as normative as well as analytical concepts; a goal to be sought, rather than a reality to be investigated'.

Such a usage, most commonly found in developing countries that hold up the experience of developed countries as 'best practice' to be attained, is evident in the South African case. After 1994, the new government has progressively put in place a set of policies that in many senses embody such a 'network ideal', as a goal to be sought or aspired to. For instance, Science and Technology policy begins from the premise that new forms of knowledge production are emerging as a consequence of globalisation, and that the appropriate policies, structures and mechanisms need to be put in place to enable South

African enterprises to 'catch up' and become globally competitive. However, these new goals and directions are tempered by the contextual realities of the legacy of apartheid – uneven and unequal development along racial lines. Policy goals are thus generally underpinned by a dual commitment to addressing the challenge of competitive integration into the global knowledge economy and, simultaneously, to contributing to equitable national economic and social development.

The key point, though, is that South Africa as a developing nation aspires to create the conditions for being globally competitive, which centre on the network enterprise and new forms of knowledge production. Critical government departments – Science and Technology (DST), Trade and Industry (DTI), Education (DoE) and Labour (DoL) – have formulated policies in line with their specific focus, aiming to steer and regulate change towards these policy ideals. Science and technology policy centres on the notion of creating a national system of innovation that can promote economic and social development. Using the network society as conceptual device enables us to understand the extent to which the notion has been adopted as a normative ideal underpinning South African policy frameworks.

Maintaining a distinction between the network society as ideal and as conceptual device also allows us to clarify the focus of the present study. The study has not attempted to use Castells's analytical framework systematically to provide a comprehensive sociological analysis of the global changes taking place in the South African context. Determining the ways in which the new organisational logic of the network enterprise is evident in South Africa is *not* the focus. Such a complex exercise remains beyond the scope of a single study, and awaits fuller treatment elsewhere.

Instead, the scope of the present monograph is more modest. It focuses on a new organisational form that has particular relevance for higher education – the technology co-operation network – and deals only with a narrow range of high technology fields. To understand this focus, we need to pause to consider the nature of the shifts currently taking place in South Africa in general and in the relationship between industry and higher education specifically.

Partial transitions and continuities

In a complex developing-country context such as South Africa's, we may expect that the transition to new economic and social forms will be partial, uneven and incomplete. As Kraak (2001) points out, much of the literature on globalisation stands accused of assuming that the transition to a new global economy is universal and takes the same form in all national contexts. Kraak instead postulates that there is far more continuity than is commonly assumed, with the social and organisational forms of the past remaining active in the present, alongside new forms, in both developed and developing countries. The network society, he argues,

> …does not totally displace old forms of social and economic organisation, but rather co-exists alongside them with the network society becoming the new commanding heights of most advanced national economies. (2001: 95)

In the South African case, we may argue, the network society is largely the new 'commanding heights' to which we aspire. Indeed, there is evidence to suggest that the new policy vision is still largely an ideal, with isolated pockets of change at the high technology end (see for instance Adam 2003, COHORT 2004).

This trend is reinforced by evidence relating to the scale and forms of research partnerships between industry and higher education, revealed in a previous component of the *Working Partnerships: Higher Education, Industry and Innovation* series. The present monograph is the final instalment of the series. An earlier study attempted to map the forms of partnership in high technology fields across the higher education system in South Africa, and is indeed intended as a companion piece to this monograph (Kruss 2005). Kruss (2005) suggests that although there have been shifts within South Africa, the emergence of new organisational forms is still only on a small scale. Given the country's complex history, there is evidence of much continuity of old organisational forms, with these old forms co-existing alongside new forms, and of different possible pathways towards common goals. The following section will review the analysis of these old and new forms of partnership developed from the mapping process, to clarify the basis for the focus of the present study.

Defining forms of partnership in the South African context

As a starting point for an empirical analysis of partnership across the higher education sector, a comprehensive working definition of the term 'partnership' was adopted, to denote any and all forms of co-operative research relationship of mutual interest between higher education and industry (Kruss 2005). A tool was then required to determine what is included under the general rubric of 'partnership' in the South African higher education sector. What are the ways in which researchers and academics describe their partnerships? Is there evidence of the new forms of networks and collaborations, or do partnerships take older, more traditional forms?

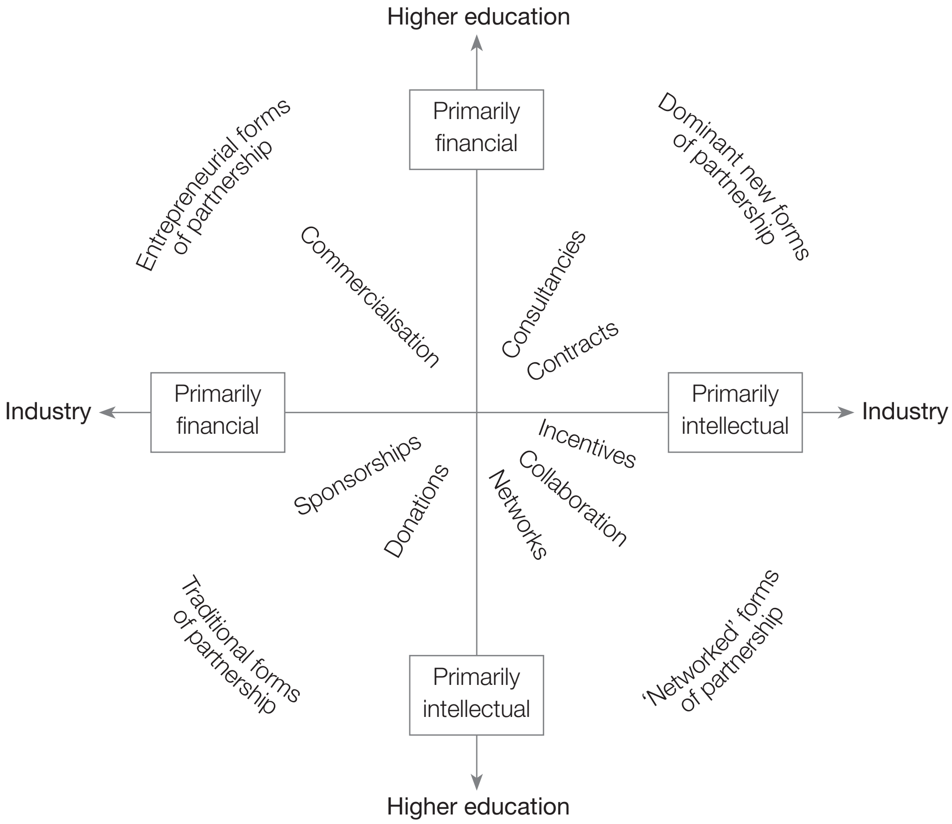
Typically, a strong tension has been identified between the imperatives of the market and the traditional knowledge imperatives of the academy (see for instance Slaughter and Leslie, 1997; Jacob and Hellström, 2000; Muller, 2001; Ravjee, 2002). An analytical matrix was constructed to represent the responses to this tension in the intersecting relationship between higher education and industry. The potentially conflicting tensions shape the forms of partnership that emerge, and can be represented diagramatically as shown in Figure 1.1. In effect, the matrix represents two intersecting continua, with the poles defined by either the primarily financial or the primarily intellectual imperatives shaping a partnership. These are not either-or opposites, because, in reality, both operate simultaneously. As Castells (2001) says of the contradictory functions of higher education, these poles represent resolutions of contradictions more strongly in favour of one particular imperative than of another.

A complex combination of these old and new forms of partnership may co-exist in any higher education institution, and indeed even within a single research entity (Kruss 2005). They are now briefly reviewed.

Traditional forms of partnership

There are traditional forms of partnership between industry and higher education that have long existed and continue to be found in present-day South Africa. Donation, one of the oldest forms, is conceptualised as benefaction or philanthropy on the part of industry, typically in the form of the endowment of a professorial chair or a building. Closely related is sponsorship, with post-graduate student research funding a core focus. This is unsurprising, given the imperative for industry to respond to socio-economic development needs in the 'new South Africa' and to strengthen their corporate social responsibility portfolios. In these two forms of partnership, the relationship between higher education

Figure 1.1 An analytical matrix of forms of partnership



and industry is primarily a financial one, and higher education is left free to continue with its intellectual projects, with few conditions imposed by its partners.

Newly dominant old forms

The numerically dominant forms of partnership currently evident across the system are consultancies and contracts, strongly shaped by higher education's financial imperatives, and, to varying degrees, by those of industry. These forms of partnership have long existed, but over the last decade have increased across the higher education system on a significantly larger scale than before. In consultancies, an individual researcher in higher education typically acts in an advisory capacity to address the immediate knowledge or technology problems of an industry, usually in exchange for individual financial benefit. Contracts may be linked to solving potentially interesting scientific problems or, more likely, to addressing a specific immediate industry problem. Contracts are primarily shaped by the need on the part of higher education to attract funding for research. They may take a variety of forms but commonly tend to be dyadic, with one industry partner and one higher education partner.

The higher education institution has a strong financial motivation for pursuing partnership, whether it is to access funds for post-graduate students, research equipment, or laboratory costs. The industry partner typically has a specific product or process problem that it wishes to have resolved, in a short period of time, but is happy to leave research to the higher education institution, as long as it provides the agreed 'deliverables'. 'Design solutions' are a related form of partnership that has emerged where technikons with appropriate technological expertise have set up centres for prototyping and testing, which offer design solutions to industry. These forms of partnership place potentially severe restrictions on the intellectual property of researchers, placing embargoes on the traditional academic products of peer-reviewed articles and post-graduate theses, for varying periods of time, in order to protect the financial interests of industry. They can thus have potentially severe negative implications for the core research function of higher education.

New forms of partnership

There is limited but growing evidence of the emergence of new entrepreneurial forms of partnership. An example of this is commercialisation, in which higher education researchers take on a strongly entrepreneurial role, attempting to commercialise prior intellectual work in the form of a spin-off company or in collaboration with an existing company willing to exploit intellectual property in the form of royalties, licences or patents, or through venture capital. Here the relationship is shaped primarily by financial imperatives for both industry and higher education, but is predicated on knowledge or technology that has been developed with varying degrees of collaboration.

Other new forms of partnership that have emerged include incentivised partnerships, with a weak form of intellectual collaboration, stimulated by government funding aimed at developing research and development and innovative capacity within South Africa, by encouraging technology transfer between higher education and industry. Collaboration partnerships have a knowledge-based linkage in which all partners make an intellectual contribution, but there may not be a financial relationship involved.

New networks

Finally, there is evidence of a small number of complex network forms of partnership existing in a minority of institutions. These are knowledge-intensive forms of partnership, and are shaped primarily by the intellectual imperatives of both industry and higher education. In such strategic partnerships, where the research concerns of higher education and industry partners coincide more strongly, there is more likely to be intellectual collaboration around the research, and there is a stronger focus on innovation of product or process.[1] Such partnerships typically take the form of networks of multiple higher education, industry, science council and funding organisations, with distinct roles and contributions, who benefit mutually but in different ways. These were identified as South African instances of the new forms of partnerships most typical of the network society logic. Castells (1996: 191) has termed such forms of partnership a 'technology co-operation network' that:

> …facilitates the acquisition of product design and production technology, enables joint production and process development, and permits generic scientific knowledge and research and development to be shared.

1 Innovation has been defined as: 'the application in practice of creative new ideas, which in many cases involves the introduction of inventions into the marketplace. In contrast, creativity is the generating and articulating of new ideas. It follows that people can be creative without being innovative. They may have ideas, or produce inventions, but may not try to win broad acceptance for them, put them to use or exploit them by turning their ideas into products and services that other people will buy or use'. (DACST 1996:15)

We could add that such sharing occurs between a number of enterprises and researchers from (several) higher education or other kinds of research institutions. The evidence suggests that in South Africa such research networks can best facilitate the innovation process (and hence, socio-economic development and global competitiveness). This is because they are most able to harness new knowledge generated in multiple fields of application, to produce new products and solutions (Kruss 2005).

It is such technology co-operation networks that form the specific focus of this monograph and the research on which it is based.

Patterns of partnership in high technology fields

The study focused on three cutting-edge high technology fields, identified in national foresight studies (DACST 1999) as critical to be developed in South Africa, to enhance global competitiveness and facilitate 'catching up'. These are biotechnology, information and communications technology (ICT), and new materials development. Kruss (2005) traces the specific policy frameworks aimed at developing research and enterprises in each of the three fields, and considers key trends in the patterns of the old and new forms of partnership which are emerging.

The analysis suggested that different forms of partnership are linked with the specific industrial sub-sectors that engage with these cross-cutting technologies. For instance, the majority of partnerships in information technology (IT) services and software development, included in the study because they were described as 'cutting edge' by their institution, took the form of contracts or consultancies. The university typically provides fundamental research that is then developed as a product in a separate, unconnected process, or it provides applied research to solve short-horizon problems. The trans-disciplinary nature of biotechnology and the centrality of networks and collaboration towards knowledge development in the field were borne out in the pattern of partnerships evident across the small emerging sector in South African higher education institutions, supported, significantly, by a substantive national policy framework and state incentivised funding. The levels of academic and industrial competition, and the mature nature of the field, with the emergence of cutting-edge nanotechnology research, have shaped the patterns of partnership in new materials development, so that sponsorships, contracts and consultancies tend to predominate, although these may be characterised by varying degrees of collaboration.

The previous study thus provided evidence to confirm that in South Africa, as a developing nation, old and new organisational forms co-exist, in a complex, uneven, and fragmented reality, and that there are differences between knowledge fields and their related industrial sub-sectors.

Understanding how networks are created in the South African context

The analysis equally reinforced evidence of the emergence of important and interesting innovative capabilities across the South African higher education system. Significant scientific advances have been made by higher education in partnership with industry that contribute to both global competitiveness and enhancing the quality of life. Moving up the global value chain depends on critical innovation, and for this to occur, new forms of partnership are desirable, along with the kind of relationships with industry that they entail (Kruss 2005). In partnerships that take the form of networks, collaboration, incentivisation and commercialisation, higher education's role is very likely to include 'open-ended intellectual inquiry' – as fundamental or strategic research. This would be motivated by the intrinsic demands of a discipline or field of knowledge, and would include multi-disciplinary partners within higher education, together with multiple industry partners. This agrees with Castells's (2001) claim that critical to developing institutions as centres of innovation is cross-fertilisation between different disciplines, together with detachment from the immediate needs of the economy. In network forms of partnership, higher education seems most able to balance its traditional intellectual imperatives with new financial imperatives, in its own long-term interests, as well as those of the industrial sector, to create the kind of innovation that enhances the economy and responds to social needs.

The present study focuses specifically on these new forms of partnership – on the co-operation networks in high technology fields that are evidence of the 'commanding heights' of global shifts in the South African context. It attempts to describe analytically the complex, contingent and 'messy' ways in which higher education institutions are creating knowledge networks, in distinct high technology fields. Through examining eleven in-depth and detailed case studies of cutting-edge practice, it will be possible to understand the forces shaping knowledge networks in the South African context specifically.

In turn, understanding how networks are created in practice can inform the ways in which higher education institutions could create knowledge networks in future. It can identify critical issues that policy-makers, institutional managers and academic researchers need to engage with, in order to provide a stronger basis for innovation.

The research approach and design

A contextualised approach to understanding networks

Within a firm, innovation and knowledge production are rooted in human learning, and consequently, involve a multitude of determinants that are difficult to quantify. Industrial sectors vary in their demands for knowledge-intensive collaboration with higher education, and in their propensity and capacity for technological innovation. A partnership with higher education institutions that has proved to be successful in one sector, for instance the telecommunications sector, may not be appropriate for another sector, such as agriculture. Individual enterprises or firms within a specific sector may also display such variation. This is particularly because there is no direct translation of what a firm may intend by its strategic decisions and the initiatives that it realises in practice (Benassi 1993). The notion that there is a single, 'best practice' path towards successful networks and innovation is thus rejected.

Without an explicit focus on technological and sectoral variables, we can understand networks only in fairly general and abstract terms. Here the concept of 'embeddedness' has been influential (Granovetter 1985). This concept implies that the institutional framework of an enterprise shapes the actions, expectations and beliefs of the social actors entering into a strategic alliance. A researcher or engineer does not act as an isolated individual, but is shaped by the organisation and culture of the firm he or she works in. Indeed, each of the partners participating in a network is embedded in distinct institutional contexts. Differences in the respective structural dynamics, modes of operation and strategic objectives of each of the partners contribute to the complexity of the interface within the network, with the potential for conflict, tension and power asymmetries. 'Embeddedness' refers to the fact that economic actions and outcomes are shaped by actors' individual relations and the structure of the overall network of relations (Grabher 1993).

Some research has suggested that the greatest barrier to collaboration between industry and higher education lies in a lack of understanding by the different partners of university, corporate or scientific norms and environments (Siegel et al. 2003:18). Thus, research needs to be clear on what drives enterprises in different industrial sectors, as well as how specific contexts of research entities shape the participation and interaction of the participants within a network.

This approach highlights the importance of analysis beginning from a socialised account of the enterprise, of the research entity, and of other intermediary partners. Examples of such partners would be science councils or regulatory bodies, whether public or private sector. It will be important to understand what 'drives' each participant in a network, how they interact, how each benefits, and what the limitations of power asymmetries on the network are – all against an understanding of their respective institutional contexts.

Adopting such an approach, the research reported in this monograph attempted to address four main questions, to illuminate the nature of the networks currently created on the cutting edge in South Africa:

- What are the knowledge, technology and economic needs that have driven a specific enterprise or research entity to enter into a strategic network between industry, higher education and other intermediary partners in South Africa?
- What is the nature of the structure and dynamics of knowledge interaction within these research networks in South Africa?
- In what ways does the knowledge interchange serve the needs and interests of the partners and in what ways are they constrained or limited?
- What are the variations and commonalities between the networks operating in each of the three technology sectors?

Three nodes of interacting partners

Castells (2001: 10) has defined a network in the simplest way as, 'a set of interconnected nodes'. The higher education industry research network has typically been analysed in terms of three nodes of interacting partners, each constructed with varying degrees of complexity. An influential model describing relations between government, higher education and industry in a knowledge economy is the 'triple helix' model proposed by Etkowitz and Leydesdorff (1997 and 2000). According to the traditional view, the university has the functions of education and research, industry has the function of production, and government has the function of regulation. In the new global context, these authors suggest that a 'triple helix' model is the most appropriate for reflecting the complex relations between the three partners. That is, each institutional sphere takes on new roles *alongside their traditional roles*: universities assume a role in economic development, translating research into economic activities; industrial firms conduct R&D activities laterally in co-operation within a group of firms, sharing knowledge in order to become more competitive, and governments play new roles in relation to higher education and industry, to promote innovation, in some cases adopting a more interventionist and in others a more laissez-faire mode.

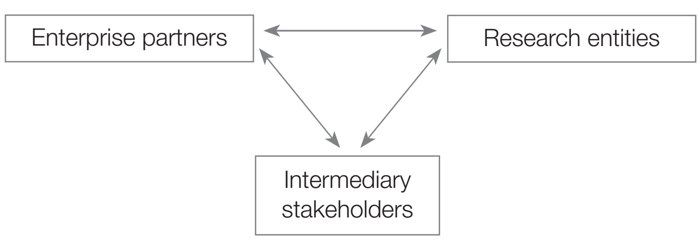
The 'triple helix' model has been widely critiqued as providing a useful starting point for analysis, but not offering sufficiently robust analytical tools or conceptual distinctions. Marceau (1996), for instance, has argued that the relationships between government, industry and higher education are more complex and diverse than suggested by this model. Echoing the notion of embeddedness, she argues:

> The players constituting all strands are multifaceted and pursue multiple and often internally conflicting goals. They also maintain vital linkages to players in other areas of the socio-economic system in which they are embedded. (1996: 252)

Akin to Castells's notion of networks within networks, is Marceau's suggestion (1996) that each of the three strands be viewed as 'complexes of activity'. For instance, there are several levels of government that have a degree of responsibility for factors influencing economic development, and governments may have many manifestations that operate simultaneously but lead in different directions. In South Africa, for example, higher education is the responsibility of the Department of Education, which is currently restructuring the system in line with the National Plan for Higher Education (2001). However, the Department of Science and Technology and the Department of Trade and Industry have been responsible for establishing key funding programmes, aimed at promoting partnerships between higher education and industry. These will in turn contribute to innovation, which has had significant influence on research in general and on partnership in particular. Likewise, an enterprise may have a complex organisational structure where parts prioritise investment in innovation and in R&D differentially. Marceau also argues that there is a diverse variety of ways of organising government, industry and higher education links, and proposes a focus on the operation of production systems and knowledge-production systems.

Data-gathering and analysis for the present research thus proceeded from the assumption that there are, potentially, three complex nodes interacting in a network. The 'enterprise' node may consist of one or more companies in an industrial sector, with one (or more) usually acting as lead enterprise, and the others as secondary enterprise partners. These may be inserted simultaneously into other networks with different goals (Castells 1996). The 'research' node likewise has a primary research entity – whether a research group, unit, institute or department within a university or technikon – and possible secondary research partners. 'Intermediary stakeholders' are primarily linked to the public sector, but, as will become evident, in a wide range of different ways, for instance, to science councils or to statutory funding agencies. The basic relationship between the three nodes may be diagrammatically represented as shown in Figure 1.2.

Figure 1.2 The three interacting nodes of a 'network'



The research design is premised on unpacking the embedded complex nature of the partners at each node, and of the structure and dynamics of the network interaction that result. Hence, it will become evident as South African cases of networks are described in the following chapters, that this simple representation of the relationship between the three nodes does not take into account the complexity of the composition of each node, and of the strength and direction of the flows of knowledge, finance, governance and personal authority between them.

In order to understand the knowledge, technology and competitive needs that drive some firms and some research entities to enter into network alliances in the three high technology fields, we required a contextualised account of both the enterprise and the research entity. What potential enterprise 'problem' (current or future product or process) was at the heart of the network, and what were the organisational forms, research and innovative capacities and commitments of the enterprise that drove it to seek strategic alliances to apply knowledge to address the problem? Likewise, we needed to understand the organisation and capacity of the research entity, and how it understood the process of generating, processing and applying knowledge. The knowledge, technology and competitive needs and interests of the intermediary stakeholders – primarily in the public sector – were less firmly in the spotlight, but were nevertheless significant.

Castells proposed, as described above, that a network's performance will depend on its 'connectedness', on a structure enabling communication between its component parts, and on its 'consistency', a sharing of interests between the networks goals and the goals of its component parts. Connectedness, the interactive relationships of a network, involve, 'common elements of technical knowledge, common codes of communication, and social relations involving mutual trust and shared social values' (Lundvall 1993: 60). These qualities take time to develop and are costly to learn, with implications for the existence and stability of a potential network. We thus needed to examine the formal structure of the network itself, and the dynamics of communication, trust and power that had developed amongst the partners, to understand its potential success or failure, and long-term prospects.

Such description, it was proposed, could contribute to understanding the processes driving the creation of networks in the three high technology fields, ultimately to inform higher education's engagement with contemporary challenges.

The case study design

Data was gathered and analysed so that a series of rich, detailed case studies of networks in the South African context could be written. At the heart of the study is a set of extensive descriptive profiles of the partners at each node of the network, allowing the reader to understand the dynamics of each. Data was gathered from organisational websites and from interviews held for this purpose.

There are many possible dimensions we could have focused on in order to understand the nature of the structure and dynamics of the network. In line with the approach adopted, and for purposes of focus, we concentrated on developing a clear sense of its strategic objectives, the ways in which the network is organised, the nature of the linkage and the channels of communication of knowledge and funding, and its phases of development. To understand the benefits and constraints of the network for the partners at each node, we examined who benefited and how, including (and not only) the tangible products and outcomes, and the perceived limitations, barriers and facilitators of the network.

Data was gathered by means of in-depth interviews with key representatives of the lead enterprise and the lead research entity active in the network. This was triangulated with short telephonic interviews with secondary enterprise and higher education partners, and with the intermediary partners, as appropriate.

Selection of case studies

The overall approach of the study stressed the need to take distinct contexts into account – whether of South Africa in general, of specific higher education contexts, or of specific knowledge fields or specific industrial sectors.

The partial transition in South Africa, the imperatives for political development and the segmentation of economic activity into high level skills, intermediate skills and low level skills sectors is significant. The history of higher education in South Africa, in particular, the institutional racialisation of the sector and the legacy of the binary divide between universities and technikons, means that we find strong institutional differentiation. There are distinct pathways and trajectories that may speak to distinct levels of economic activity.

Given this differentiated history, only a few 'research' universities displayed clear evidence of potential cases of knowledge or technology co-operation networks in the three fields of focus. However, selecting cases only from these historically advantaged institutions would have provided a relatively skewed account of what was possible for the higher education system as a whole. An attempt was thus made to identify a contextually defined set of network projects, stratified to take into account the way in which economic, racial and educational divides are reflected in research capacity across the South African higher education system. The pre-2005 configuration of universities and technikons is used throughout this monograph – thirty five universities and technikons existed in 2003, prior to the restructuring of the institutional landscape. A master population of ten universities and six technikons in which there were potential instances of networks was identified, drawing on the empirical study of partnerships across the higher education sector (Kruss 2005). The selection was then made from this institutional configuration:

- Five cases were selected from the universities that displayed significant strengths in research capacity and evidence of network forms of knowledge-intensive partnership in one or more of the three fields;
- Three cases were selected from universities with emergent research capacity, which typically had evidence of networks in one specific field; and
- Three cases were selected from technikons, noting the distinct historical mandate of technikons regarding technology and their recent shift to research, as well as the distinct way in which technikons are applying technology to development issues.

It is important to bear in mind that this does not mean that the case studies selected are representative of all the network partnerships that exist in the field. Rather, they were selected purposively from a set of cases that had earlier been identified by their institution as 'cutting edge', as part of a scan of partnerships across the higher education system conducted in early 2003. This means that we need to proceed with caution when generalising from these individual cases to characterise the South African case as a whole. Nevertheless, they do provide a significant window onto cutting edge practice in the relationship between industry and higher education in South Africa, and are hence of considerable value.

The working definition of a 'network' for selection purposes was a partnership that was knowledge intensive, involved knowledge collaboration, involved multiple and diverse partners, and had the goal of innovation of product or process. A set of eleven research entities – whether in the form of a research centre, institute, unit, group or programme – was identified using this process and each was requested to identify a specific research project.

Some of the research entities refused to participate in the study, citing confidentiality agreements with their industry partners. It was notable that these were all in the field of new materials development, and this concern with secrecy and confidentiality will be explored more fully in Chapter 4.

It will become apparent that these selection criteria were not watertight, given that the process relied ultimately on the goodwill – and interpretation – of the directors of the research entities. Once the in-depth investigation was completed, there were cases that were more appropriately classified as contracts, or as incentivised forms of partnership. Their inclusion serves both to highlight the features of networks, and to illustrate the scarcity of such new organisational forms across the higher education sector in South Africa.

This monograph

This monograph has three distinct but interrelated central chapters, describing and analysing networks in each of the three fields of focus – biotechnology, ICT and new materials development. Appendix A summarises the focus and the key partners of the eleven cases in the study. It is intended as a reference point for each of the chapters.

Each chapter interrogates and synthesises three or four case studies, using the approach outlined here, in relation to the related policy and industrial contexts. There is a degree of variation, in that the author of each chapter has adopted a distinct approach to the analysis of the case studies, either by case or by theme. What is common is that each chapter describes the knowledge, technology and competitive needs of specific industrial sectors that motivated an enterprise aimed at building networks with higher education and other intermediary partners. They profile the partners at each node of the network and analyse the structure and dynamics of their interaction. Lastly, each considers symmetries of benefit and outcome, and the likely future trajectory of the networks.

The final chapter (Chapter 5) returns to consider the insights we can draw from the descriptive analysis of the ways in which networks are created. How can this inform higher education's challenge to respond to new imperatives, to create knowledge networks on a larger scale in future in the South African context?

CHAPTER 2

Biotechnology research and technology networks: the dynamics of competition and co-operation

Gilton Klerck

Biotechnology: knowledge field, industrial sector and policy framework

Biotechnology as a knowledge field

Universities and government laboratories were the birthplace of the biotechnology industry, and they continue to be the source of the new technology that sustains it globally.[1] The 'basic science' component of the biotechnology industry has proved to be vitally important to its initial success and subsequent expansion. Biotechnology is an exemplar of the new forms of knowledge production that are based on multi-disciplinary approaches and problem solving in the context of application.

The development of biotechnology as a form of knowledge production is characterised by the convergence of a diverse set of skills from a variety of disciplines. The foundational research – most notably the discovery of recombinant DNA methods and cell-infusion technology that creates monoclonal antibodies – drew primarily on molecular biology and immunology. These early discoveries were so path-breaking that for a time they had an inherent exclusivity: in the absence of close interaction with those involved in the research, knowledge was extremely difficult to transfer. This has changed dramatically, however, as the science diffused rapidly over time.

Many new areas of science – ranging from genetics, biochemistry, cell biology, general medicine and computer science to physics and the optical sciences – have become inextricably involved in the processes of knowledge production. Biotechnology is therefore not a discipline or an industry *per se*, but rather a set of technologies relevant to a wide range of disciplines and industries (Powell 2002).

Biotechnology is one of the most promising frontier technologies for the near future. It is generally defined as a cluster of techniques that use biological systems – living organisms or their derivatives – to make or modify products or processes for specific use (Mboniswa 2002). Biotechnology has evolved through three distinct phases or generations. First-generation biotechnology has been used for many years in the making of products such as cheese, yoghurt and vinegar. Second-generation biotechnology involves techniques such as mutagenesis and the selection of strains and cultivars to improve metabolite and crop yields. In this generation, the manipulation of micro-organisms generated products such as amino acids and antibiotics. South Africa has a history of engagement with

1 This chapter is based on case studies written by Michael Cosser, Carel Garisch, Rachmat Omar and Gilton Klerck.

traditional biotechnology, using its techniques to produce globally competitive products in the form of beer brewing, wine, dairy and other fermentation products, new animal breeds and plant varieties, some of which are used commercially all over the world. A notable process in second-generation biotechnology is a commercial procedure for producing lysine.

South Africa's response to recent advances in biotechnology has been more limited, particularly over the last 25 years, with the emergence of genetics and genomic sciences – the third generation, which is associated with recombinant DNA technology. Building on the discovery of its structure, molecular biology has enabled a detailed understanding and manipulation of DNA. DNA cloning, for example, allows scientists to remove genes of known traits from micro-organisms and insert them into agricultural products. For some time the technology was not applicable to large-scale sets of genes, proteins, ribonucleic acid (RNA) and other molecules within the cell. However, since the early 1990s technologies have been developed that are able to reveal the sequences, proteins and transcripts of genomes as diverse as those of human, fly, mouse, and worm, and a host of pathogens, such as tuberculosis. Large-scale data-production of this nature has created challenges relating to the interpretation of large biological datasets. These challenges have intensified with the success of the Human Genome Project.

The cognitive structure entailed in knowledge generation varies between fields. In the fast-moving field of biotechnology, knowledge creation is complex and rapidly expanding, with a wide dispersal of sources of expertise (Powell 2002). In addition, the knowledge base of the biotechnology industry is to a significant extent tacit or non-codified in nature. This makes knowledge transfer more demanding and requires close, personal co-operation between (especially) engineers and scientists. Scientists have to stay at the forefront of knowledge-seeking and technological development. Developing countries are at a significant disadvantage in this regard and are confronted by a host of obstacles in their efforts to gain a foothold in the biotechnological sciences. Generally speaking, these countries have not succeeded in expanding their scientific base and research infrastructure of biotechnology beyond a few academic institutions and individual scientists. In South Africa, the majority of biotechnology research projects are based at historically advantaged institutions (Walwyn 2003). Sophisticated infrastructure and internationally recognised researchers enable these institutions to attract the lion's share of investment from the private and public sectors for biotechnological research.

Biotechnology as an industrial sector

Globally, the science underlying the field of biotechnology has its origins in discoveries made in university laboratories in the early 1970s. These breakthroughs contained considerable commercial potential and were initially exploited by science-based start-up firms or dedicated biotechnology firms established in the mid to late 1970s (Powell 2002).

Since many processes that involve microbial or enzymatic catalysts are considered environmentally friendly and cost-effective, companies are increasingly exploring the advantages of biotechnology in the production of a range of commodities. This exploration is done mainly through acquiring biotechnology units, or through collaboration with such organisations. In knowledge-intensive fields such as biotechnology, where rich rewards are gained from innovation and spectacular losses can be incurred from obsolescence, the core capabilities of firms are increasingly based on knowledge-seeking and knowledge-creation. Successful firms in the biotechnology field position themselves as the hubs at the centre of overlapping networks, encouraging numerous research collaborations and gaining from multiple projects in various stages of development (Powell 2002). In other words, economic competition in this sector resembles a 'learning race'.

The multi-disciplinary character of this field of learning has made a range of inter-organisational linkages vital to the diffusion and absorption of knowledge. The industrial application of biotechnology is dependent on collaboration between science, engineering and technology institutions and the private sector. Internationally, the field is at the forefront of the growth in the number and scope of inter-organisational collaboration. Since biotechnology depends on an array of different competencies and types of knowledge, enterprises in this sector rarely develop new technologies in the absence of a range of collaborative partnerships with external organisations. The locus of innovation is therefore found in knowledge-intensive networks of learning rather than in individual firms. As inter-organisational relations shape the structure of an industry, the nature of competition is fundamentally altered as the rate of product and process innovation is drastically accelerated. Collaboration itself becomes a dimension of competition.

A firm's portfolio of collaborations is both a strategic resource and a signal to the market of the quality of its services and products. Competence at managing network relations is therefore a central determinant of success in the knowledge economy (Powell 2002). The internal capabilities of a firm are significantly enhanced by external collaboration, and biotechnology firms are thus characterised by a continuous search for partners and by on-going efforts to boost their collaborative capacity.

The key to the competitiveness of the developed economies is to be found in the acquisition of the most advanced, skill- and technology-intensive industries. These industries have a high value-added content and are less sensitive to price competition, since the market emphasis is on product quality and design. Many companies and public institutions elsewhere in the world offer products and services that have arisen from the new biotechnology. In the USA alone, there are 300 public biotechnology companies with a market capitalisation of $353 billion and an annual turnover of $22 billion. In the developing economies, the dominant industries are mainly mature, non-science-based sectors, benefiting either from local natural resources or from cheap labour (DTI 2002). Their capacity to innovate and lead technological development is limited. Design and production methods are standardised and productivity growth is slow. The major form of competition is price competition, depending predominantly on labour costs or natural resource availability. Newly industrialised economies such as South Africa are somewhere in between these two extremes. While they have managed to establish some capital- and skill-intensive industries with a higher processing level than peripheral economies, their capital goods sector is small and continues to be dominated by the developed economies.

There is considerable evidence that the value of higher education research as an external source of technical knowledge is particularly significant among high-technology firms. The benefits of public research differ between industries, relying amongst other things on the science-dependency of innovations, the manner in which innovations are generated, and whether the innovation process is discovery- or design-driven. Biotechnology generally ranks high on all these criteria. Innovation systems are embedded not only geographically and technologically, but also in terms of industrial sector – that is, a 'sectoral' innovation-system. Where systematic evidence exists, it suggests that strategic research partnerships may be more important in sectors dominated by smaller firms (such as biotechnology) than in those characterised by larger enterprises (such as pharmaceuticals). Small firms account for a disproportionate share of new product innovations, given their low R&D expenditures. In South Africa, small, medium and micro enterprises (SMMEs) accounted for 66 per cent of industry partners under THRIP (Technology and Human Resources for Industry Programme) and Innovation Fund-incentivised projects in the biotechnology sector (HSRC 2003).

Although South Africa does not have a developed biotechnology sector, the technology cuts across a number of existing industrial sectors such as agriculture, fishing, manufacturing and mining. The state of the biotechnology sector could be attributed to the absence of a critical mass in the necessary skills, and a lack of organisational resources and funding. It will require greater investment by the state and the private sector to enhance competition with established firms in the world market. Current policy development shows a growing commitment by the South African government to encourage investment in biotechnology and to develop a competitive industry. Given the knowledge-intensive forms of collaboration and the science-dependent nature of innovation in biotechnology, creating a viable industry in South Africa raises a number of complex resource, policy and institutional considerations, the dynamics of which will become evident in different ways in the four cases that will be described and analysed in this chapter.

Biotechnology and industrial policy

The South African government's macro-economic, industrial, labour market and investment policies are geared towards the attainment of certain goals. These include high-technology, high value-added exports, and the rationalisation of education and training systems to produce a high-skill workforce. Another goal is a restructured manufacturing sector, with a shift in the basis of competition from price factors to product quality and variety, responsiveness to consumer demand, and so on. The National Research and Development Strategy recommends that South Africa adopt a strategic approach that, 'capitalises on the established natural resources base while actively pursuing stronger manufacturing, information technology and biotechnology strategies' (DACST 2002a: 29). The focus is on advanced manufacturing and on creating a knowledge base for industrial innovation.

The goal of a more knowledge-intensive strategy in R&D is in line with economic development plans embodied in the government's Integrated Manufacturing Strategy, the National Plan for Higher Education, and the National Skills Development Strategy. The Integrated Manufacturing Strategy is premised on the claim that accelerated economic growth demands 'knowledge intensity' – that is, 'utilising and developing the knowledge and skills of our people in order to integrate information and communication technologies, innovation and knowledge intensive services into the functioning of the economy as a whole' (DTI 2002: 3). This strategy emphasises partnerships and networks, technology and innovation, the provision of an enabling institutional environment for R&D, and targeted innovation support for strategic areas such as biotechnology.

There was, however, a need to supplement industrial strategies drafted in such general terms that sector-specific characteristics were largely glossed over. The government is currently in the process of developing and implementing a number of sector-specific strategies. The National Biotechnology Strategy, for instance, recognises that, unlike other developing nations such as Cuba, Brazil and China, South Africa has, 'failed to extract value from the more recent advances in biotechnology' (DACST 2002b: 1), and hence, aims to realise the national potential for contributing to economic development. It provides for the establishment of Biotechnology Regional Innovation Centres (BRICs) in different provinces – to promote R&D and to provide entrepreneurial services, technology platforms, intellectual property management, and business incubation. Each BRIC constitutes a consortium consisting of academic institutions, private institutions and research councils specialising in specific areas, in line with national development imperatives, local expertise and market opportunities. Three key centres were awarded to leverage biotechnology opportunities in 2003. Biopad BRIC in the Gauteng region focuses on animal health and industry- or environment-related biotechnology. Ecobio BRIC in KwaZulu-Natal concentrates on human health and bioprocessing, with a central plant biotechnology area. Cape Biotech Initiative BRIC in the Western Cape focuses on human health and bioprocessing. These centres are proposed as nuclei for the development of biotechnology platforms, from which a range of businesses (including black economic empowerment) offering new products and services can be launched (DACST 2002b).

These BRICs act as interconnected yet independent nodes, linked through the National Bioinformatics Network, which is being set up to provide computational power, genome interpretation facilities, and networking links between the BRICs and other research institutions. The National Bioinformatics Network operates in association with, but independently of, the South African National Bioinformatics Institute (SANBI) based at the University of the Western Cape. Overseeing the development of biotechnology in South Africa is the Biotechnology Advisory Committee, reporting to the National Advisory Committee on Innovation (NACI) and to the Department of Science and Technology (DST). In addition, the DST aims to establish a National Bio-information Facility, while NACI will be setting up a Biotechnology Advising Centre and a Bio-ethics Committee to address the extremely controversial issues raised by some research.

Government thus aims to play a key role in steering innovation, by encouraging the formation of networks and funding the process of technology development in the phases before firms are prepared to take risks. It does this by targeting resources in key areas of high potential and ensuring that there are, 'sufficient financing, networking and institutional arrangements in place to deliver value from the investments' (DACST 2002a: 37). The National Research Foundation (NRF) regards biotechnology as one of the key areas to stimulate South Africa's industrial and global competitiveness. In the three years up to 2003, it had invested close to R180 million in biotechnology (see www.dst.gov.za). The growth of its investment is reflected in programmes such as THRIP, which increased total funding grants from R19.2 million in 2001 to R32 million in 2003. Funding in focus-area programmes increased from R5.3 million to R8.8 million in the same period. Investment by the Innovation Fund in biotechnology also increased from close to R25 million to nearly R32 million in 2003, while support for students increased to almost R3 million (www.dst.gov.za). Specific areas that are funded in biotechnology include bioinformatics, molecular biology, genomics, proteomics, immunology, genetics, molecular modelling, and structural biology.

It is in the context of these substantial government attempts to stimulate a biotechnology industrial sector in South Africa – by promoting research and technology transfer – that our focus now turns to consider four case studies of biotechnology networks.

The four biotechnology case studies and their associated industrial sub-sectors

Appendix A shows the partners and focus areas of each of the cases. Only one case utilises third generation bioinformatics; two use second generation techniques in the agricultural and forestry sectors. The fourth, as will become evident, is not a classic biotechnology case, although its participants in the water sector describe it as such.

This section will describe the industrial sub-sector associated with each case, to lay the basis for understanding the dynamics of competition motivating enterprises to seek research collaboration with higher education institutions.

The water industry

South Africa is largely semi-arid and prone to recurring droughts (and occasional serious floods). Access to safe drinking water is a right granted to all citizens of the country by the new constitution and is an important component of the post-apartheid government's reconstruction and development plans. The water industry is charged with the responsibility of eliminating past inequities in water provision by increasing both the efficiency and scale of its services (www.wrc.org.za). A comprehensive statutory and institutional framework has been established to regulate the provision of water services. The National Water Resources Strategy reflects the new multi-disciplinary and integrated approach to managing scarce water resources (www.dwaf.gov.za). The Water Services Act (1997) provides, amongst other things, for the fair and transparent provision of water services, and the rights of access to a basic water supply. It also spells out the duties of water service providers. The National Water Act of 1998 regulates the management and sustainable use of water resources, and provides for the devolution of decision-making to the local level and the establishment of Water-User Associations to ensure more equitable allocations of water among user groups. The Water Research Commission (WRC) has made a significant contribution to the development of the capacity of the water sector, the broadening of the country's water-centred R&D base, and the direction and funding of research on critical issues (see www.wrc.org.za). Its operations are organised around a number of strategic areas that guide investment in water-centred knowledge, and are based on a portfolio of key water-related needs.

It is in this sectoral context that we can situate the first case study, the water membrane network. It involves co-operative relations between engineers from the Water and Membrane Technology Group (WMTG) at the Durban Institute of Technology (DIT) and scientists from the Institute of Polymer Science (IPS) at the University of Stellenbosch (US). In addition to these academics, the network involves collaborative relations with the Water Research Commission (WRC), the Amatola Water Board in East London, and the Pollution Research Group (PRG) at the University of Natal in Durban. The water membrane network is an integral part of a wider network – involving a whole host of local and international organisations – focused on the removal of effluents from water used by industries and municipalities. The network evolved specifically to adapt an imported capillary ultra-filtration system for potable water production to South African conditions. A membrane filtration process was developed to clarify and disinfect water in a one-step operation without the addition of chemicals (www.sun.ac.za). This simple-to-operate, low-pressure ultra-filtration process was tested for four years and produces bacteria-free, safe drinking water. The technology was also tested, with promising results, on water containing high concentrations of natural organic material. Current research is aimed at process development and automation, non-chemical pre-treatment, de-fouling and flow destabilisation strategies.

Agriculture and agro-chemicals

Agriculture in South Africa, like other sectors of the economy, is highly centralised. Although there are more than 60 000 farmers in the country, employing almost a million workers, the market is dominated by a handful of large conglomerates. These are either central co-operatives or agri-businesses with significant downstream operations that give them a stake in other sectors of the economy. The current trade regime has effectively raised the cost of key intermediate products, thus militating against labour-intensive downstream activities. When output prices increase at a slower rate than the price of inputs (a cost-price squeeze) – as has been the case in South Africa over the last five decades – farm profits come under increasing pressure.

In the past, government support of white farmers, in the form of subsidised credit and capital, was very high. The marketing and distribution of most agricultural products were, until the late 1980s, conducted according to statutory single-channel marketing systems that required producers to register with, and sell their produce to, a central body (for example, the Maize Board). The main policy shifts since 1994 include the deregulation of agricultural marketing and production, changes in the fiscal policies relating to agriculture, the restructuring of public assets and privatisation, the promulgation of the Marketing of Agricultural Products Act (1996) and trade policy reform. The overriding objectives are to correct the injustices of apartheid and to enhance the international competitiveness of the sector.

Short-term opportunities for the agricultural sector are shaped by the need to become competitive as government subsidies are withdrawn, and to gain a foothold in international markets. Economic liberalisation and the deregulation of the agricultural marketing system have strengthened some sub-sectors, such as fruit and wine production, while others have been weakened and rendered highly vulnerable to economic and policy pressures. These shifts have compelled farmers to become more self-reliant, innovative and efficient. Increasingly, government support is primarily geared towards the promotion of agriculture and related sectors through research, technology development and technology transfer. Through its wide network of research institutes and experimental farms, the Agricultural Research Council (ARC) is central to providing a strong scientific base and a broadly distributed technology-transfer capacity for the entire agricultural industry.

Biotechnology, although potentially controversial, is particularly significant as regards global competitiveness in the agricultural sector. It is used in South Africa in developing crops that are resistant to drought and infections, to incorporate essential elements such as amino acids and vitamins into foods such as sorghum and maize, and to improve animal health.

It is in relation to such dynamics that we can analyse the second case, the mycorrhizal[2] network, focused on mycorrhizal research and development processes. The isolation and production of quality arbuscular mycorrhizal fungal (AMF) inoculants and their effective application to particular plants and soil types characterise the research foci and activities. The benefits afforded plants from mycorrhizal symbioses can be characterised either agronomically by increased growth and yield, or ecologically by improved fitness (that is, by reproductive ability and drought-stress tolerance). In either case, the benefit accrues primarily because mycorrhizal fungi form a critical linkage between plant roots and the soil, increasing the effective absorptive surface area of the plant. A significant part of this research is conducted through multi-disciplinary research teams. At present the focus of the researchers in the Amphigro consortium (described below) is on the innovation of process and techniques, and on the accruing of intellectual property with regard to the isolation and large-scale production of high-quality, indigenous AMF inoculants for application in a range of sectors.

2 Mycorrhizae are symbiotic or slightly pathogenic fungi that grow in association with the roots of a plant.

Forestry

South Africa has developed one of the largest cultivated forestry resources in the world. Production from commercial plantations was valued at almost R2.6 billion in 2000 (www.dwaf.gov.za). When combined with the processed products, industry turnover was about R12.8 billion in the same year. Collectively, the forestry sector employed about 100 000 people in 2000, with about 60 000 in the primary sector of growing and harvesting, and the balance in the processing sectors (milling, pulp and paper, mining timber and poles, and board products). In addition to satisfying a growing local demand and expanding its export base, the forestry industry is also charged with the responsibility of promoting rural development and economic empowerment through a small-growers programme. The vast majority of the more than 18 000 emerging black-owned timber-growing firms operate through schemes run under the auspices of Sappi Forests, Mondi Forests and the South African Wattle Growers' Union.

The past ten years have seen a reduction in the land available for commercial forestry as the Department of Water Affairs and Forestry (DWAF) has endeavoured to limit the impact of plantations on the environment and to enhance community involvement in and ownership of the industry. This, together with the emergence of tree diseases, threatened to undermine the financial viability of the commercial forestry industry and gave impetus to a forestry biotechnology 'revolution'. The overall policy objective is to establish a demographically representative, competitive, and value-adding forestry sector (see www.dwaf.gov.za). By ensuring that the industry is exposed to international and domestic market forces, the policy aims to foster a competitive environment for local wood products and to avoid protecting inefficient firms. Overall, the forestry industry now has little protection against foreign trade, with current import tariff protection on timber and pulp at zero, and on paper products, five per cent.

There is a marked degree of concentration of ownership in commercial forestry in South Africa, together with a high degree of vertical integration. Some reasons are: first, the long period between investment and return tends to favour those with large capital resources. Second, the need for secure returns on investment in capital-intensive processing plants demands an adequate resource base for a secure and timely supply of raw materials. A third reason was the availability of large parcels of land in a market that was distorted by apartheid land laws (see www.dwaf.gov.za). Fourth, the scale of capital investment required, particularly in the pulp sector, precludes many small operators from becoming involved in sub-sectors in timber processing. There is, nevertheless, significant opportunity for smaller enterprises to become involved in secondary processing and value-adding activities. Given the costs of forestry, government policy deems that it is in the public interest to discourage the export of raw materials and to encourage beneficiation.

The commercial forestry sector in South Africa is dominated by two large companies: Mondi Forests and Sappi Forests. These two enterprises are among the largest timber producers in the southern hemisphere, and Sappi Limited is the world's leading producer of coated fine paper. Besides these companies, there are about 2 000 private timber growers in the country. Competitive dynamics within the industry must be understood in the context of two broad phases in the forestry industry value-chain: the growing and harvesting of trees and the production of pulp for paper products and wood for timber products. The first phase is pre-competitive. Forestry enterprises are intent on planting and growing healthy trees that will satisfy the needs of end-users (www.mondiforests.co.za). There is a large degree of collaboration between enterprises at this level. The second phase, however, is highly competitive, where companies compete on the basis of productivity, yield, quality, and price. Almost 60 per cent (nine million cubic metres) of the wood produced in South Africa per year is processed for pulp and paper (www.dwaf.gov.za).

In forestry (excluding forest products), the investment in R&D is about 3 per cent of industry turnover (www.dwaf.gov.za). Grants from the National Research Foundation support R&D indirectly (through research grants to individual academics) and directly (through the Forestry Development Programme). Government currently funds about 30 per cent of R&D in forestry, compared with about 50 per cent in 1990/91. The priority fields of research range from tree breeding through applied silviculture, and climate and soils to management solutions, forest hydrology and protection.

The third case study, on the tree-protection network, focuses on the pre-competitive phase, and the production of trees. Major forestry companies involved are Mondi Forests, Sappi Forests, the Central Timber Co-operative, Hans Merenski, and Global Forestry Products. Intermediary partners are Forestry South Africa (FSA) and the Department of Water Affairs and Forestry. In an attempt to remain economically viable and improve production, the forest industry established the Tree Protection Co-operative Programme (TPCP) under the directorship of a prominent tree pathologist at the University of Pretoria. This programme was formed to combat the spread of pathogens – initially reactively, through attempts to limit the damage they could do, but increasingly, proactively, through attempts (such as cloning) to pre-empt the spread of pathogens via the cultivation of trees that are resistant to pests and pathogens. The TPCP, with considerable support from Pretoria University, developed into a prominent research programme and has subsequently been absorbed into the Forestry and Agricultural Biotechnology Institute (FABI), within which it is but one amongst many research programmes.

Bioinformatics and pharmaceuticals

The firms that initially translated the science of biotechnology into feasible technologies and new pharmaceutical products faced a host of challenges. In addition to the usual difficulties faced by start-up firms, biotechnology firms required large amounts of capital to fund costly R&D, as well as assistance in management functions and in conducting clinical trials, in dealing with the regulatory approval process, and in manufacturing, marketing, distribution and sales (Powell 2002: 266).

The advent of biotechnology in general, and human genome decoding in particular, raised exciting opportunities for the rapid development of target-specific drugs. This excitement is clearly mirrored in the rising fortunes of pharmaceutical companies on global stock markets. Since it is hoped that genome decoding will allow researchers to understand the genetic mutations that cause illness, pharmaceutical companies are positioning themselves to benefit from the decoding of the human genome.

A distinctive characteristic of the pharmaceutical industry is its high degree of centralisation and its extensive dependence on R&D. Major multi-national pharmaceutical companies are continually buying out biotechnology companies or merging with other established firms in the industry. It is not surprising, therefore, that large multi-national corporations dominate the pharmaceutical market. A general decline in tariff barriers and the introduction of price controls have further intensified competitive pressures in South Africa's pharmaceutical industry.

Developments in information technology have created an interface between computers and biology, known as bioinformatics, and expertise in this area is fast becoming one of the most sought-after skills in modern biology. In the context of the genome data explosion, and with the development of fields such as genomics and proteomics, bioinformatics has become an indispensable technology for molecular biologists. At least 25 per cent of pharmaceutical R&D and biology research efforts in developing countries is devoted to processing information about biology which is stored in computerised form. The challenge for South Africa is to develop significant human capital in bioinformatics to support the development of a biotechnology industry. The multi-disciplinary nature of the field of bioinformatics can however be an obstacle in converting existing molecular biologists into proficient and capable bioinformaticists. Coupled with the high costs of software, hardware, technical maintenance and systems support, many developing countries may not be able to realise their biotechnology potential fully, either academically or economically, because they lack the ability to utilise bioinformatics as a technology to support and co-develop with molecular biology-oriented research programmes.

Price and quality considerations interact in complex ways in bioinformatics. Price is undoubtedly important and one of the advantages for South African companies is that they can produce at lower costs than competitors – for example, in the USA. Price is not always the overriding consideration, however. For many researchers and clients, the primary consideration is quality, in the form of accuracy. The latter is crucial for drawing proper conclusions, particularly since products often have a broad spectrum of applications. Differences between the products of different companies are important and product preferences are likely to be determined by the trade-off the client is willing to make between speed and accuracy.

The fourth case study, the bioinformatics network, involves the Human Expressed Gene and Disease Project at the South African Bioinformatics Institute (SANBI), at the University of the Western Cape. The research work entails, 'the mapping and analysis of alternative expression products, gene expression states and disease gene detection' (www.sanbi.ac.za). The focus of the wider partnership is on using cutting-edge technology in bioinformatics research to generate solutions to biological research problems and to contribute to further development of software that will speed up genetic and biotechnology research. SANBI produces the research outputs, which are commercialised and sold by a spin-off company, Electric Genetics, which produces software that enables pharmaceutical companies to speed up the drug discovery process and to reduce the risks and costs associated with R&D.

The structure and dynamics of knowledge interaction within the networks

The role of competition, outlined here in relation to the primary industrial sub-sector within which the enterprises in each case are located, is a vital motivator in the search for new partners, technologies and products. Changes in the level of competition are a primary driving force behind the constitution and re-constitution of networks. In this section we will examine how the four networks are structured, organised and managed – through formal and informal processes – to facilitate the flow of knowledge, over time. A primary concern here is an exposition of the competitive, technological and knowledge interests that led the organisations at each node into collaborative partnerships. The network dynamics will be considered in terms of roles and the flows of knowledge, funding and power.

The water membrane network

A significant stimulus for the development of co-operative relations with higher education institutions is the low levels of R&D capacity within the water industry itself. Historically, water R&D in South Africa was moderately funded, limited in scope, confined to a few institutions, and lacked strategic leadership to identify priority areas and encourage technology transfer.

In South Africa's rural areas, the water at the disposal of communities is often unfit for direct human consumption due to high levels of microbial and other contaminants (such as cholera). This places unique demands on water researchers and service providers. Broader collaborative networks are therefore necessary to develop the technologies that will allow industry partners – in this case mostly public sector water boards – to carry out their mandates.

Public sector industry partners

Although it receives funding from government, the Amatola Water Board is continuously seeking ways to become more self-reliant. It does not possess the capacity or resources to rely exclusively on its own R&D, which is limited largely to problem-solving activities. This has encouraged it to establish partnerships and to view all such initiatives from a commercial angle. A primary criterion for involvement in partnerships is the commercial potential of a new technology or process. For Amatola Water, the profits generated through a joint venture reduce the costs of water supply to its customers and provide it with better long-term financial security. These partnerships also allow Amatola Water to reap benefits from R&D more quickly than those water boards working on their own.

The qualities of the capillary ultra-filtration system dovetailed neatly with some of the primary concerns of Amatola Water. Since some of the water sources in its sphere of operation could not be treated easily by conventional methods, the Board saw a useful application for membrane technology in its filtration functions. As the first 'client' of the research network, Amatola Water provides the facilities necessary to test and scale-up prototypes and assists in sorting out minor problems in the filtration system. As such, it provides the technology with a record of accomplishment, which is necessary to support a bid for its commercialisation.

Since the membrane technologies being used at the Institute of Polymer Science (IPS) at Stellenbosh University can be developed only to a laboratory scale, it required the skills of engineers to fine-tune and optimise the capillary ultra-filtration system for large-scale applications. The Water and Membrane Technology Group (WTMG) at the Durban Institute of Technology (DIT) possesses stronger practical skills and has a greater 'hands-on' approach to membrane research, which proved to be vital. Existing personal relationships, as well as the different orientations of universities and technikons towards knowledge generation and application, encouraged the partnership between the WMTG and the IPS. Combining these two sets of skills – the more analytical skills found at Stellenbosch University and the more applied skills found at DIT – produced a highly productive form of collaboration. On their own, neither the university nor the technikon would have been able to develop water membrane technology to the point where industry would have become interested. Long-term commitment from an industry partner usually requires researchers to have completed the design and operational stages of an innovation. The higher education node of the network is therefore based on the need to integrate pure and applied research in order to produce a commercially viable technology.

In contrast to the Stellenbosch group's established reputation and long-term record of partnerships with industry, the DIT group is still a little-known entity and is often compelled to offer its services free of charge. The WMTG frequently has to carry the costs of initial tests and process-development, hoping that it will reap some rewards in the long term. External contract research grants account for the bulk of the WMTG's research income. Capital equipment worth about R1 million, operating expenses, and subsidies for post-graduate students are all derived from external funds.

An intermediary to promote capacity-building partnerships

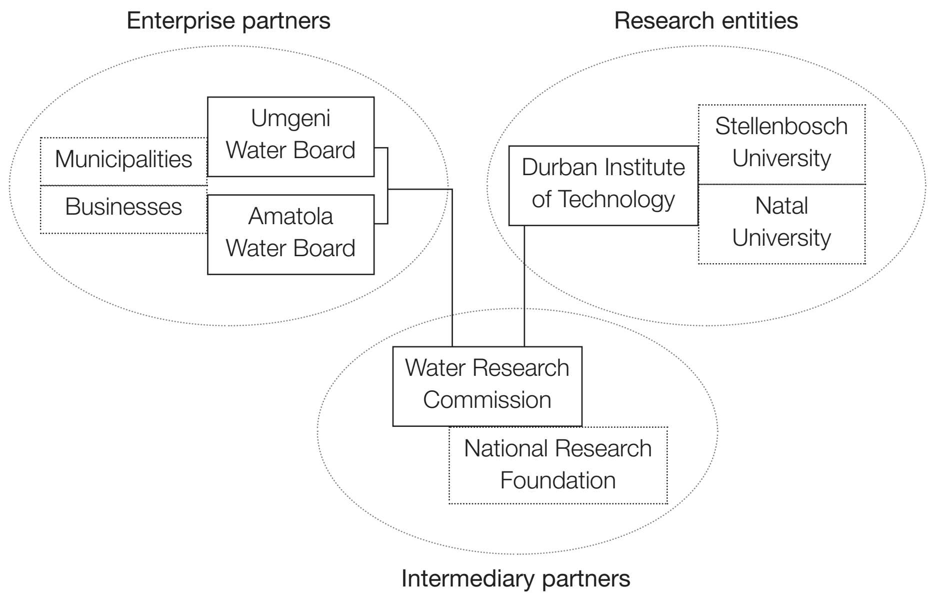
The funding criteria of both the National Research Foundation and the WRC compel higher education institutions to establish capacity-building partnerships. The WRC does not undertake research itself, but enters into agreements with specialist organisations to carry out research projects. In 2000, the WRC's financial support to 318 different research projects totalled R62.1 million (www.wrc.org.za), of which universities received the largest share – 51.57 per cent of the total number of contracts. WRC funds are withheld if the parties do not establish co-operative relations or deliver on capacity-building requirements, which means that historically advantaged institutions are compelled to co-operate with historically disadvantaged institutions. According to one manager, the limited funds of the WRC compel it to channel finances towards applied research with a practical focus. The only fundamental research that is funded (about ten per cent of WRC funding) is research relating to problems that arise within a specific component of a larger applied research project.

The fundamental research necessary to develop the capillary ultra-filtration system was conducted at Stellenbosch University. Subsequent funding from the WRC targeted the applied research component at DIT. This filtration system attracted WRC funding because it is easy to operate, requires no chemical additives, and produces water of a high quality. In contrast, conventional filtration systems need constant monitoring and there is far more that can go wrong. Furthermore, the capillary ultra-filtration system operates most cost-effectively on a small-scale and is therefore an ideal water treatment technology for small rural communities.

The WRC acts as an intermediary between the higher education institutions and water-users (see Figure 2.1). The higher education partners in this network interact with industries and municipalities indirectly through the WRC, especially in the early stages of technological development. The direct relationships with industry are of a much more limited duration and entail less intensive forms of knowledge exchange. Typically, these relationships involve running on-site trials, to solve a particular problem faced by an industry within a specified period of time. The WRC does get involved in commercialisation and, 'acts as a champion of the network if the other parties cannot do it themselves'.

This intermediary role of the WRC resolves at least three problems faced by higher education institutions engaged in partnerships with industry. Firstly, it allows for more realistic timetables than those normally demanded by industry. Secondly, the continuity provided by the WRC overcomes the problems associated with staff turnover in industry. Thirdly, the presence of the WRC eliminates the need for multiple and complex contractual negotiations with industry partners. In addition, the WRC has a significant influence over the water industry and is able to encourage collaboration within the network. As a result, the higher education partners in the membrane network regularly draw on their resources and expertise.

Figure 2.1 The water membrane network



A flexible network structure

As the partnership between the two research units unfolded, other academic departments at both the DIT and Stellenbosch became actively involved. The development of a capillary ultra-filtration system requires the expertise of micro-biologists, biochemists, analytical chemists and chemical engineers. The latter are regarded as particularly important in forging effective links with industry. This multi-disciplinary focus is not only a result of the knowledge demands of industry, but also an inherent characteristic of polymer science. The particular mix of inter-disciplinary expertise that is required is established on the basis of need and of existing personal relationships. This gives the network a certain inherent flexibility to respond to changes in the demands for knowledge and expertise on a range of projects.

At any given point in time, the network structure will depend on the nature of the challenges that confront the industry or service provider in question. For example, the WMTG may co-operate closely with the IPS at Stellenbosch on one project and then collaborate strongly with the Pollution Research Group at the University of Kwa-Zulu Natal on another. The membrane network is therefore a product of the problems it attempts to address. The complimentarities that have developed over time between the partners have served to strengthen these relationships. Prior experience of co-operative relations with industry proved to be vital for the effective involvement of academics. In other words, involvement in one partnership with industry provides the skills necessary for greater involvement in others.

Bringing additional partners into the network significantly reduces the costs and risks associated with commercialisation, and expands the amount of available expertise. For example, at the time of the research, there were plans to draw the Port Elizabeth and Border technikons (as they then were) into the membrane network. They would provide access to laboratory and testing facilities that are situated closer to East London, as well as access to local applied skills. Like the existing members, the new partners would be expected to add value through the resources and knowledge they bring. The meshing of skills – analytical skills from the IPS, applied skills from the technikons, and practical skills from Amatola Water – and associated knowledge transfers were regarded by all the respondents in the case study as vital ingredients for the success of the membrane network. The multi-directional flows of knowledge also mean that both the research institutes and the water suppliers contribute to the development of membrane technologies.

Strong personal relationships and trust

The water membrane network displays key features that characterise the organisational dynamics of most networks. Networks typically generate internal mechanisms for the monitoring of individual performance and for the resolution of problems that may arise. Initially, the membrane network was largely governed in an informal manner and depended heavily on personal relationships, with the partners contributing collectively to the application of knowledge and the development and transfer of technology. All the respondents mentioned the notion of a 'team' working towards the same goal in their accounts of the network structure, which was described as devoid of overt hierarchies. These control mechanisms changed significantly as the project unfolded. The largely unofficial and spontaneous division of labour has, in several respects, become more formalised over time. Greater formality is a result of provisions in the research contracts entered into with the WRC, the need to monitor the progress made in the pilot project with Amatola Water, and the desire to commercialise the technology.

These formal or contractual relations, however, constitute only a small part of the overall functioning of the network. Informal and personal relationships continue to create trust, reciprocity and productive competition, and remain absolutely vital in channelling the network's resources towards the ultimate objective: an efficient and commercially viable water-filtration system. The cross-fertilisation of ideas is in large measure the result of the pivotal role played by the directors of the IPS and the WMTG. As one director put it: 'although our relationship has gone through various strains when things do not work out, the chemistry between the people concerned is very important'. 'Strains' typically arise from the different expectations of the industry and higher education partners in relation to setting deadlines and long-term objectives. Business decisions emphasise short time horizons and cost savings, and industry hence places considerable pressure on the higher education partners to conduct research that leads to the attainment of practical results and commercial benefits, within a limited period of time. The higher education respondents recognised the need to conduct 'relevant' research, but were concerned about the potential loss of institutional autonomy and academic freedom. Such disagreements are seen as a vital part of the learning process in a network, and mechanisms were developed to manage these 'creative tensions'.

The approach to patents clearly illustrates the significance of tacit knowledge transfer within this network. Although the network partners have registered some patents, less emphasis than before is now placed on patenting new technologies. The high costs involved in registering a patent are the first reason. Secondly, and more importantly, the water-filtration systems developed are highly dependent on tacit knowledge and practical expertise. For example, there is a high probability that a water-treatment facility that functions effectively at one point in a river, will not deliver the same results if moved a few kilometres downstream. As one project leader explained: 'there is no such a thing as a 'device' that a person can buy, plug it in, and it works. The expertise has to go with it. You can buy all the components and the instructions, but unless you have the expertise you will not be able to make these water treatment technologies work.'

Commercialisation of the new technology

Commercialisation constitutes an important watershed in the evolution of network governance. At present, a lack of financial resources and mechanical equipment means that there is still no water purification 'product' that can be sold to industry and service providers. The capillary ultra-filtration system requires a capital outlay of about R6 million before it can be effectively commercialised. As the researchers developed the capillary ultra-filtration system to an appropriate scale and started presenting the results of their trial runs, interest in the technology grew. For example, members of Amatola Water became interested in the filtration system after hearing of its potential benefits at a workshop on small water-treatment systems. It is hoped that successful trials of the filtration system at the Nahoon Dam near East London will lay the basis for an expansion of the industry node of the network, which is vital for developing a market for a commercialised filtration system.

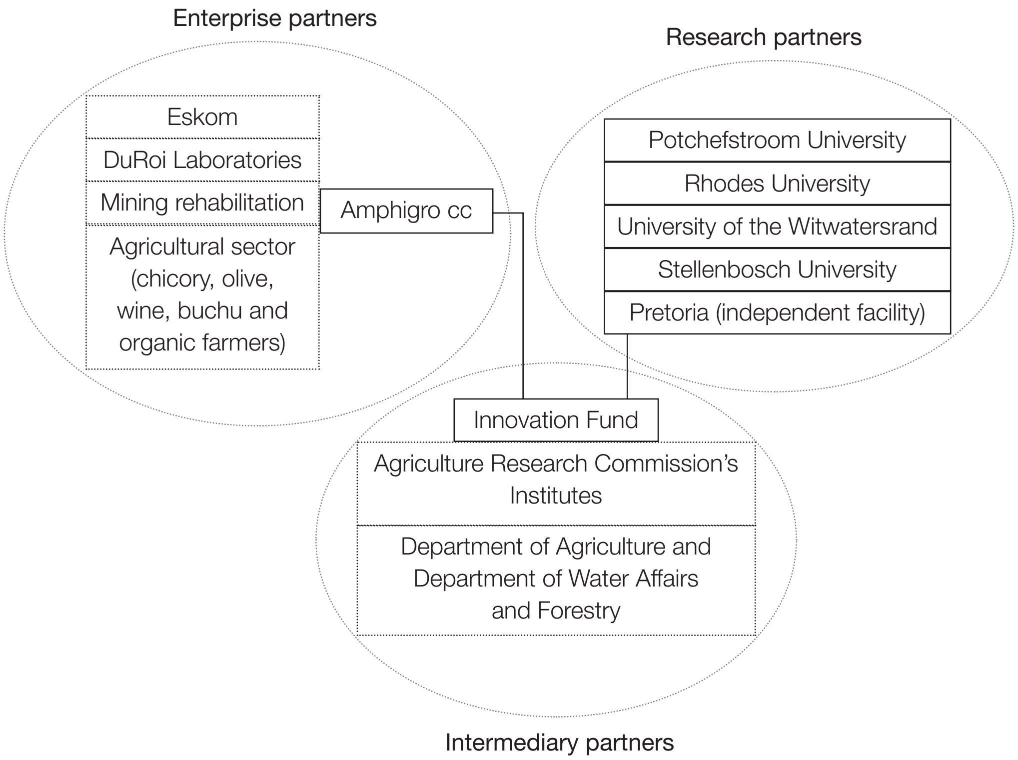
Once the commercial viability of the new technology has been established, a joint venture will be formed to regulate the relations among the various partners. The memorandum of understanding that provides for the establishment of a joint venture states that membrane technologies must be made available to small, micro and medium enterprises (SMMEs), and that part of the profits must be distributed to the higher education institutions. A lesson learnt the hard way, according to the higher education respondents, is that academics should not get directly involved in the commercialisation process. The technology will be licensed to users through the WRC. Once full industrial tests are completed, Amatola Water will provide the joint venture with the capital to produce the filtration system on a commercial basis. In exchange, Amatola Water has the right of first refusal on the commercial product and might obtain a provisional licence to operate the system. According to an industry partner, the memorandum is, 'like a marriage contract', binding the parties together while safeguarding their respective interests in the project.

The mycorrhizal network

Strategic alliances in the mycorrhizal network involve a range of organisations in various sectors and industries with the aim of developing processes and products, and conducting field trials. The objective of this network is to use indigenous arbuscular mycorrhizal fungi (AMF), isolated from local soils, in developing a technology for the large-scale production of high quality AMF inoculum (see www.amphigro.com). Given the scope of this task, it was decided to involve specific members of the Southern African Mycorrhizal Working Group, which was formed in 1995, to investigate the status of AMF research in South Africa. Initially, the relations between the parties were loosely structured and organised. After receiving funding from the Innovation Fund, Amphigro became operational as an entity, and the need for a more formalised organisational structure increased. It would appear that opposing positions developed with regard to a formal structure for the research entity: whether to settle for centralised as opposed to autonomous facilities linked to the divergent needs and preferences of individual researchers. These positions clearly have different implications for institutional ties and, as will become evident, they continue to influence the network dynamics.

Amphigro's structural make-up, in its current dual status as intellectual property development enterprise and Innovation Fund project administrative vehicle, comprises five sites or laboratories based in Grahamstown, Johannesburg, Potchefstroom, Pretoria and Stellenbosch. Four of these are loosely linked to universities, and one has independent status (see Figure 2.2). Amphigro is the R&D company, which all researchers joined as equal sharing members. Amphigro's commercial wing, Ammerce, is a consulting company, responsible for handling research contracts. In practice, these contracts are relatively small-scale and predominantly represent the contract work which members were engaged in prior to the establishment of Amphigro. All AMF projects conducted outside the scope of the Innovation Fund project are executed through Ammerce.

Figure 2.2 The mycorrhizal network



Specialised applied research in multi-disciplinary teams

In the light of the strong emphasis on the development of processes and techniques to isolate, produce and test inoculum for commercial purposes, it would appear that the Amphigro consortium has invested more strongly in applied, as opposed to basic, research. In practice, however, the members of the consortium appreciate the need to maintain a dynamic balance between these two. The main disciplines in which Amphigro researchers are grounded are mycology[3] and plant physiology. Contributions from other disciplines and areas of specialisation – such as botany, soil ecology, microbiology and organic farming practices – have also been incorporated. These contributions are either solicited from colleagues or occur in the course of the work of multi-disciplinary project teams. Each Amphigro researcher has acquired a unique body of grounded knowledge through individual experience, which cannot be fully captured in and conveyed by formal means, such as research papers, reports or presentations. These features typically signify the attributes of tacit knowledge, cumulatively acquired by a particular individual within a specific application or context. Given the problems associated with the transfer of such knowledge, these researchers are not immediately interchangeable – resulting in their relative structural independence.

3 The study of fungi

Amphigro as dominant knowledge partner
This network stands out with regard to the structure and pattern of interaction between the organisations at the three nodes. Concerted efforts have been made to establish a durable trade-off between autonomy and dependence. Each consortium member is in control of its own specific project and R&D activities, in collaboration with a specific set of enterprise partners.

In general, the enterprise partners have a limited role. They carry out the monitoring of the trials and collection of data, while Amphigro researchers interpret the results with a view to product validation. Material transfer agreements are signed at the early stages to ensure that Amphigro retains ownership of intellectual property rights. It is evident, therefore, that these collaborative partnerships are Amphigro-driven and occur on Amphigro's terms. The nature of Amphigro's collaborative relationships thus means that companies act more like prospective clients than knowledge-based network partners.

Amphigro dictates the nature and scope of the R&D focus and activities, within the guidelines and administrative framework associated with the Innovation Fund grant. Given Amphigro's self-contained status as both R&D institute and prospective commercial enterprise, alliances with the universities are strategic only in the sense of the universities receiving infrastructural support such as laboratories and technology, and the institute having access to a pool of potential employees drawn from post-graduate students. In some cases, the institutions' administrative structures are used for the procurement of raw materials in order to benefit from university supplier discounts. Such linkages are clearly not knowledge-based.

Strategic alliances with intermediary organisations are of a secondary nature in that such entities do not influence the nature and direction of R&D activities in any direct way. In effect, a number of the intermediary organisations fall into the category of secondary enterprise partners as well as being prospective clients – for example, Chicory South Africa (CSA), which is geared to adding value to chicory-based products. South Africa is currently one of the world's largest producers of chicory, and the total annual production of between 12 000 and 14 000 tons of dried chicory root is consumed locally (see www.chicory.co.za). With a capacity of about 5 000 tonnes per day, CSA constitutes one of the biggest chicory-drying enterprises of its kind. An ongoing concern in the industry revolves around keeping production costs down and improving agricultural and factory efficiency. It is within this context that, when approached about six years ago by Amphigro's Rhodes University-linked laboratory to evaluate the effects of AMF on chicory growth, CSA expressed interest in a collaborative venture. The collaboration between Rhodes's organic chemistry department and CSA involves the study of the inulin[4] content in the chicory plant, with regard to its use as a food additive aimed at boosting the body's immune system. The long-term objective is commercialisation, once the extraction technology has been developed at laboratory level, with CSA's relation to the research being primarily that of a disseminator of information to farmers.

Similarly, Amphigro's relationship with the ARC's Institute for Soil, Climate and Water (ISCW) involves applied mycorrhizal research around particular agricultural problems, such as the application of mycorrhiza by emerging farmers who cannot afford fertilisers, and collaboration in field trials. This is in line with the mandate of the ISCW to promote the sustainable and integrated use and management of natural resources such as soil and water.

4 A (fructose-type) polysaccharide found in the roots of certain composite plants

Communication and knowledge exchange between the five researchers

The mycorrhizal consortium can be seen as a horizontally integrated 'five-pointed star' structure. The project co-ordinator is the only hierarchical feature, with each laboratory enjoying a relatively high degree of autonomy. Separation is manifest in two distinct senses. The first of these is the geographical separation of the laboratories and personnel, with a consequent impact on co-operation, collaboration and knowledge sharing among Amphigro colleagues. Second is the differentiation between laboratories in terms of R&D focus and associated activities within the overall project framework, with product-specific specialisation by researchers in line with their particular areas of interest and tied to catering for potential niche markets.

The decentralised nature of Amphigro facilities appears to have little impact on the effective functioning and performance of the mycorrhizal network. All internal decision-making about research issues, resources and network management is, by all accounts, conducted in a consensus-seeking manner at the formal quarterly consortium meetings, which are a mechanism for accountability and knowledge transfer. Should deadlocks arise, legal recourse can be sought within the framework provided by the close corporation. Mycorrhizal science is accessible to all parties in the network through formal and informal modes and channels of knowledge exchange. Trust would seem to be guaranteed through the high degree of transparency derived from the formal reporting mechanisms and processes. However, by some accounts, the initial milieu of openness evident during the early days of the working group has given way to a more guarded atmosphere, as the project has approached the end of its funding cycle.

Interface with external partners

As far as relationships of trust and reciprocity with external partners of the mycorrhizal network, such as the ARC and CSA, are concerned, these occur within the context of formal agreements – clarifying and defining roles and responsibilities – concluded prior to collaboration. The ARC, for example, has conducted more than 90 joint-research projects with local universities and has well-established channels of communication and monitoring mechanisms (see www.arc.agric.za). While the signing of a material transfer agreement guarantees intellectual property ownership to Amphigro, it reciprocates by offering the bulking of the inoculum to the collaborating enterprise, upon successful conclusion of field-test trials.

Similarly, Chicory SA's agricultural department provides the interface between farmers and manufacturing operations. It has established collaborative relationships with various institutions and enterprises, including Rhodes University (mainly the departments of organic chemistry and botany), the ARC (this is a historical linkage with regard to seed production and distribution), product companies like Bayers (which provides an advisory service), and Amphigro (through the Rhodes University-linked laboratory). Rhodes University provided the AMF inoculants, while CSA did the planting and monitoring of the inoculated shoots. The collection of data during the test trials and the interpretation of results at their conclusion were done by the Grahamstown researcher. The field trials produced a very dramatic increase in yield, which could be substantively related to the symbiotic effect of the mycorrhizae. These results are guaranteed to translate into an increase in profit-taking once the inoculants are commercially applied (the exact figures and estimates have been withheld upon request from CSA).

With regard to field-test collaboration, partners are almost always located relatively close to Amphigro sites. For example, CSA is only about an hour's drive from Rhodes

University, while Rustenburg wine estate and the Costa olive farm are literally minutes away from Stellenbosch University. In instances where distance is a factor, the effect would appear to be compensated for in some measure by the nature of the processes involved in the field trials. Although the initial decision-making and setting-up of the trials obviously involved the physical presence of, and oversight by, Amphigro researchers, their continuous hands-on involvement is not required in the day-to-day monitoring and data-collection processes, which can be carried out by R&D personnel or designated staff members of the participating enterprises. Alternatively, the evaluation could be conducted by Amphigro researchers in closer proximity to the field-trial partner, as in the case of the vine- and olive-field trials currently being conducted by the Stellenbosch University staff with inoculum provided by the Johannesburg researcher.

The challenges of shifting to commercialisation

From a national perspective, the application of indigenous AMF on a commercial basis promises vast benefits – economic (more efficient crop production), social (greater food security) and environmental (increased food production without associated increases in land use, fertilisers, and so on). Commercialisation is the ultimate goal of Amphigro. Since it faces no immediate competition in terms of indigenous AMF species, it can be viewed as having effectively cornered this particular market in South Africa. In reality, however, an established South African AMF market does not as yet exist because, on the whole, little awareness and appreciation exist of the benefits to be derived from the commercial application of AMF. The development of a South African market is a critical challenge faced by Amphigro if commercialisation is to succeed.

With a product that has been developed and successfully tested, the question to be resolved concerns the most cost-effective means of delivering the product to the market. A sense of uncertainty has prevailed as to Amphigro's fundamental nature. Though the same individuals are involved, Amphigro has developed into two separate entities with differential structures and dynamics. There is 'Amphigro-as-project' – a consortium-based Innovation Fund-governed entity, and there is 'Amphigro-as-enterprise' – a commercially registered production company that existed prior to the project.

As far as Amphigro-as-project is concerned, the Innovation Fund grant was instrumental in getting the researchers to define their respective roles in relation to the memorandum of understanding, rethinking the project's relationship to the universities, and considering the implications for intellectual property ownership regarding past and future research contributions.

With regard to Amphigro-as-enterprise, the winding up of the Innovation Fund project at the end of 2003 increased pressure on the members to provide answers to critical organisational issues raised by the commercialisation process. A key aspect of these developments concerns the nature of future Amphigro-university linkages. Whereas the initial relationship focused on structural support, this is now being viewed as a limiting factor and structural separation from the universities is being considered.

A further problem, not fully resolved at the outset, relates to the issue of entitlement to intellectual property rights. Patents apply to living organisms only if these are genetically modified (which mycorrhizae are not). Consequently, only aspects pertaining to AMF R&D – for example, the process itself – can be considered for patenting. Cost factors constitute a significant constraint in this regard. Adding to the complexity is that although all the consortium members have the same status by virtue of being equal partners, entitled to the same benefits, pressure arises from disproportionate levels of contribution by individual researchers. There is a tendency for researchers to prefer individual ownership of the products they have developed. The situation seems further complicated by the fact that some collaborative partnerships with industry existed prior to the project.

Thus, with the focus of the network to date on 'substantiated' process and product development, market development represents the next frontier as the enterprise readies itself for commercialisation. With Amphigro's imminent transformation from a research project to a fully-fledged commercial enterprise, the organisational landscape is set to change fundamentally.

The tree-protection network

The tree-protection network allows forestry companies to have access, in a cost-effective manner, to advanced research expertise on tree pathology. One of the managers at Mondi Forests is pressing for strategic alliances with higher education institutions. The nature of his work depends on close co-operation with academic researchers to improve the quality of the fibre that is Mondi's key output. Through this network, Mondi has strategic alliances with Sappi, its main competitor, and with other smaller forestry companies, with co-operatives like the Natal Co-operative Timber Company (NCTC), with Forestry SA, and with other forestry research institutes like the Institute for Commercial Forestry Research (ICFR) at Natal University. Some of these organisations are strange bedfellows who would not, were it not for the Tree Protection Co-operative Programme (TPCP), ordinarily be collaborating with one another.

Collaborative research to enhance the competitive edge

In a competitive environment such as that in which South African forestry finds itself, technological innovation is imperative for the sector's continued survival and growth. Innovation also plays a key role in reducing the environmental and social costs of forestry. Growing healthy trees that yield quality fibre is the core business of Mondi Forests. The turnover of the R&D component of Mondi Limited was R18 307 984 in 2003, the bulk of which goes to tree improvement (R8.2 million), technical services (R6 million), and Forest Owners' Association research (R3.5 million). Mondi sets a great deal of store by its involvement in the TPCP as the primary mechanism for inserting the leading edge of science into business. Mondi Forests sees the TPCP's primary function as providing its technical department with resources to avert the heavy losses that tree pests and pathogens can inflict.

A recent technology that the industry relies on is DNA fingerprinting, used to reproduce trees resistant to pests and pathogens. Mondi does some fingerprinting of clones, but the extent to which it is able to conduct its own R&D is limited. It is simply too costly for companies, even those of the size of Mondi – let alone the smaller companies – to appoint their own pathologists to prevent tree diseases. The TPCP, through the FABI, has a DNA sequence machine and a micro-arrayer system, which cost over R1 million each. Mondi's competitive edge is therefore vitally dependent on the R&D and risk-management strategies provided by the TPCP.

The two intermediary stakeholders are Forestry SA (FSA) and the Department of Water Affairs and Forestry (DWAF). Forestry SA acts as a spokesperson for the industry, interacting with government at the policy formulation and legislative levels and lobbying various government departments on behalf of the industry. It also acts as a broker to industry, identifying priority issues and assisting in the determination of effective responses. In addition, FSA undertakes small-scale analyses of data and disseminates information to companies (see www.forestry.co.za). The role of the DWAF in the network is largely one of oversight. As the body regulating the forestry industry in South Africa, it takes a keen interest in the economic viability of the industry, but not at the expense of its own environmental and social sustainability. In its mission statement, the DWAF commits itself to, 'managing and sustaining our forests, using the best scientific practice in a participatory and sustainable manner' (see www.dwaf.gov.za).

Multi-disciplinary applied biotechnology research

There is general appreciation of the fact that competent scientists, professionals and technicians are necessary to ensure that the forestry sector is soundly managed, and that prompt and rapid innovation keeps it that way. Much of the research conducted by a biotechnology research institute such as FABI is both multi-disciplinary and applied in nature. The primary objectives of FABI are to promote the broad field of plant biotechnology through an interdisciplinary approach and close linkages to a wide range of academic departments, and to undertake research of the highest possible calibre, while simultaneously providing short- and longer-term benefits to the forestry and agricultural sectors (see www.up.ac.za). FABI is managed by a management committee, an advisory committee, and a board of control comprised of the chairperson of the NCTC, the executive director of the Forest Owners' Association, the vice-rector in charge of research at the University of Pretoria, as well as their Dean of the Faculty of Natural and Agricultural Sciences, and the director of FABI.

However, FABI does not appear to be entirely satisfied with the current dispensation in which the demands of knowledge production and of industry are potentially, and sometimes actually, at odds with each other. The Institute has generated a spin-off company in North Carolina, but would also like to see the establishment of a local company, housed on or near the campus of the University of Pretoria. This company would manage and market the biotechnology which FABI produces, and act as an incubator of further biotechnological capacity and as a broker between FABI and the forestry industry. The desire to establish such a company does not imply that FABI wants to commercialise its research beyond 'selling' its science to the industry partners who fund it. FABI's concern is simply that biotechnology needs an infrastructure beyond the university to ensure its sustainability.

Patenting its discoveries, such as diagnostic tools, has been considered, but this is both very expensive and very competitive. For the present, then, FABI is content to find solutions to the problems that its forestry partners present for analysis. Such solutions are offered in a pre-competitive environment in which industry players can use the information provided to their competitive advantage. All major forestry companies have well-established, in-house applied research divisions. Despite these resources, the research is still done by FABI and the development by industry in the R&D equation that underpins the TPCP network.

The Institute is, however, increasingly moving from a reactive to a more proactive role in addressing pathogenic phenomena. Such pro-activeness is typically stimulated by the way in which the forestry industry responds to the occurrence of a disease or pest (such as the wood-wasp, sirex). Diseases or disease-carrying insects are often introduced into South Africa from other continents. Hence, FABI needs to anticipate the introduction of pathogens into the country by researching exotic tree diseases, their dissemination patterns in different trees, different soil types, different climatic zones, and so on. This shift from cure to prevention was taken up in the name-change to the Tree Protection

Co-operative Programme (TPCP). Such a shift does not signal the abandonment of the reactive approach, for pathogens will not necessarily be readily detectable. Rather, it means an extension of FABI's capacity to include more sophisticated disease control, embracing such techniques as DNA fingerprinting and sequencing for the development of tree varieties and clones that will be resistant to pests and diseases that may compromise their health in the future.

One of the major benefits to the TPCP's being run from its position at the core of a world-renowned research institute is its ability to obtain funding from the Innovation Fund, THRIP, the National Research Foundation, and Pretoria University itself. The University of Pretoria funds much of the activity of the TPCP by default, since it is FABI's primary funder (66 per cent of FABI's budget). Industry partners – particularly Mondi and Sappi – are also important funders. In fact, Mondi sponsors the Chair of Forest Pathology at FABI, and has recently committed itself to a further five-year sponsorship contract. In its latest biennial report, FABI lists 41 sponsors of its research, ranging from local forestry companies and forestry and fruit organisations (such as the Central Timber Co-operative, the Banana Growers Association of South Africa, the Citrus Growers Association, Forestry South Africa, the South African Wattle Growers Union, and the Wheat Cereals Trust) to international companies, foreign governments and South African government departments.

The Institute for Commercial Forestry Research (ICFR), a privately funded and privately owned institute hosted by the University of Natal, is financed via a collective funding mechanism co-ordinated by Forestry SA. FABI and the ICFR are not directly in partnership with each other, nor do they appear to be in competition with each other; their interaction is mediated through their involvement in the network. Since FABI and ICFR are both funded by industry, since all partners in the network operate within a pre-competitive environment, and since FABI and ICFR distinguish their research agendas on a regular interpersonal basis, their joint participation in the network is viable.

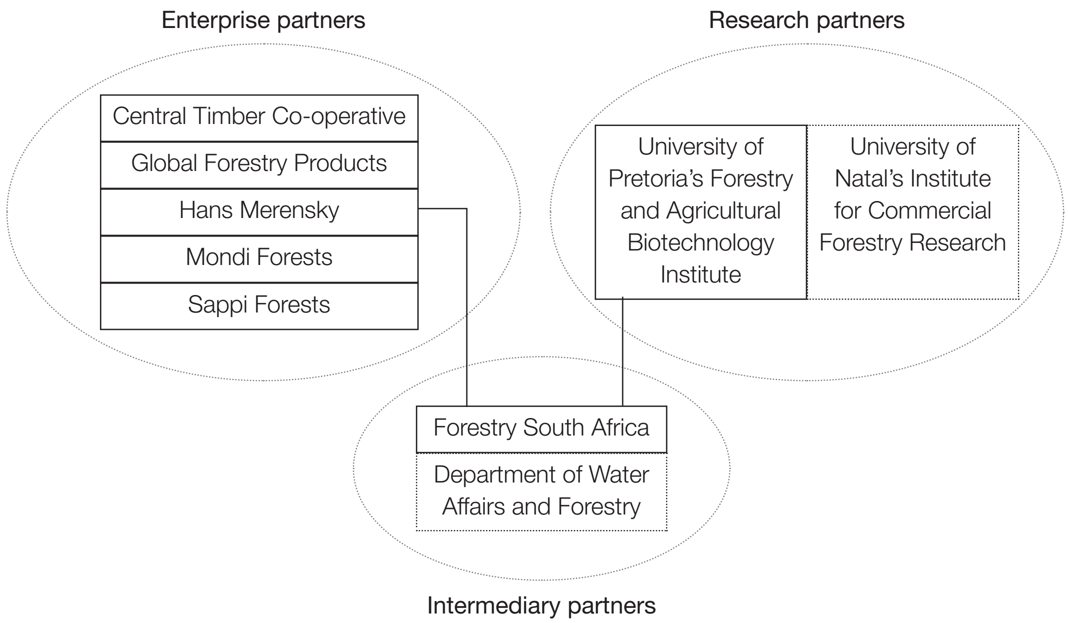
While the ICFR has been involved with the TPCP since the former's inception in 1990, it is clear from both sides that the potential for competition was present, and had to be managed appropriately. The ICFR, it would appear, has shed some of the biological aspects of its research into trees – such as entomology – in favour of silviculture, though it is not clear how voluntary a shedding this has been. ICFR and FABI communicate regularly, and seemingly amicably, about their research, which serves to eliminate duplication.

A 'membership' network structure

Participation within the TPCP is by membership. Until recently, full membership was open only to growers with a minimum area of land under plantation. This provision has recently been amended, however, to allow smaller growers to become members. The TPCP has a board and a finance committee, which meet annually, complemented by informal interaction between the partners during the course of the year.

The TPCP network has grown over the years, but has not shed any partners (see Figure 2.3). An important element implicit in this network is the set of personal relationships between the current Director of the TPCP and the industry partners, all of whom have cited the Director's extraordinary charisma, energy and integrity as the reason for the success of the network. In fact, some of the partners believe that the Director, with his international scientific rating (A2), is the pivot around which the TPCP revolves, and that his sudden departure could signal the dissolution of the network. The importance of personality in the operation of this network cannot be overemphasised. Beyond charisma, a key ingredient is experience, in that the Director has worked with the forestry industry for twenty years, and has established levels of trust and a modus operandi for collaboration that are seemingly irreplaceable.

Figure 2.3 The tree-protection network



The two-dimensional conception of Figure 2.3 does not indicate the dynamics that underpin the network operation. The partnership is a co-operative, which suggests that it is a mechanism for bringing together all stakeholders in the forestry industry under one roof. There is no sense that any of the partners at the three nodes differs in status from the others, or benefits at the expense of the others. However, the mere fact that the network revolves around one charismatic individual does mean that other individuals can engage with that person, and with others in the network, at different levels to influence the course of events. A strongly collegial relationship between Mondi and FABI, for example, may well impact on the quality of the information that FABI provides about a particular problem – notwithstanding the fact that such information is formally communicated to other stakeholders. Publicly, in other words, TPCP network interaction is pre-competitive; privately there may well be competitive elements to it.

The primary business of a university is, moreover, to educate students, and FABI is justifiably proud of its academic record, priding itself on the number of MSc and PhD students it has graduated through the University of Pretoria (35 doctorates in the last ten years) and on their contributions to science. The primary business of industry partners is to make money. From FABI's perspective, industry is a potential exploiter of university research, using cheap labour to achieve a particular goal. From industry's perspective, the focus on student training is a distraction from what should be its major focus – satisfying client needs. The management of this tension is one of the key challenges facing research institutes like FABI, which has constantly to combat the 'short-termism' of industry by looking past it to the achievement of its own core objectives. A suggestion from one of the respondents was that FABI should establish an independent company, allied to the research agenda of the TPCP, to deal directly with industry and therefore to mediate the pressures exerted by the business community.

A pre-competitive research forum

Despite the above-mentioned tensions, the TPCP network provides a forum where companies which would not normally share information discuss issues of common interest. It is understood that the knowledge generated in the TPCP is pre-competitive, dealing with challenges facing the entire industry, which means that the stakeholders are prepared to share their knowledge. This is to their long-term advantage – indeed it could ultimately be to their detriment not to share this knowledge. To this extent, the TPCP is not merely a convenient structure but a logical necessity for the industry, providing a unique service that would be inaccessible to stakeholders operating outside of the network. This implies that this whole is greater than the sum of its parts.

Key conditions that ensure the success of the TPCP appear to be present. First, the assumption behind the network is that it provides a mechanism for achieving stakeholder objectives that any one partner on their own could not achieve. There is, then, value added through the operation of the partnership that accelerates the sector's movement up the value-chain. Secondly, the network has a 'champion' to promote the cause of partnerships and to manage their dynamics. Thirdly, the network is based on high levels of trust and mutual respect. Fourthly, the network hinges on a 'win-win' philosophy, where all derive tangible benefits. Finally, the network took time to develop and to flourish – although the TPCP was formally constituted in 1990, the key research and informal relationships that underpinned its establishment are the product of over fifteen years of work.

The balance between the three nodes of the network in the case of the TPCP is marked. The champion plays such a key role that he is the pivot on which the network turns. The fine balance that this implies is at once a strength and a potential flaw. While the leader is confident that he has a successor and that a succession plan is in place, his successor may not embody the essential ingredients – such as international scientific rating and significant experience in tree pathology – that are needed for the perpetuation and future development of the network.

The bioinformatics network

The international network around the Human Expressed Gene and Disease project based at the South African Bioinformatics Institute (SANBI) forms part of a broader network aimed at promoting the biotechnology industry in South Africa through the provision of genomic information, computational biology and analytical tools.

The need for collaborative relations between higher education and commercial enterprises in this network stems from a number of sources. Firstly, the specific technologies developed by SANBI, such as the gene detection systems, are regarded as groundbreaking work in the field of genomics and bioinformatics. These achievements were central in convincing national and international players of the merits of the R&D networks initiated by SANBI. Secondly, the alliances form part of a strategy to create intellectual capacity in areas that support and provide innovation in biotechnology and bioinformatics. The demand for bioinformatics is increasing with the growth of national biotechnology initiatives and the needs of biotechnology projects undertaken through BRIC development activity. Thirdly, restricted communications access via the internet prohibited the import of large databases into South Africa and high-level communication between research sites. These limitations constrain competitive involvement in international projects and local capacity development.

Funding and scientific imperatives

SANBI's activities fall into four main categories: research, biotechnology development, service provision, and training and education. In terms of research, SANBI is developing systems to discover novel genes, and to analyse the evolution of genomes and the genes within them. With regard to biotechnology development, SANBI is developing innovative expression databases and using them to determine the modes of action of cellular and pathogen systems for drug development. As far as service provision is concerned, SANBI is developing a Bioinformatics Analysis Site to ensure up-to-date access to databases and research tools. Lastly, SANBI is involved in a range of capacity-building and academic teaching programmes, including training of postgraduate students and a joint initiative with the Medical Research Council, to establish a Bioinformatics Capacity Development Unit to provide genome data to academic, medical and commercial research scientists. SANBI's relationship with the San Diego Supercomputer Center (SDSC) allows it to draw on the Cray SV1 supercomputer, which is regarded as a major boost to South Africa's biotechnology infrastructure and gives students valuable access to supercomputing time. One of the major contributions that the SDSC has made to advancing science is by shortening the time it takes to develop new drug treatments. SANBI was also centrally involved in the creation in 2001 of the 'South African Genomics Platform', a network of genomic scientists who collaborate in researching key areas where genomics and bioinformatics can have an impact on South African science and be of national benefit.

The business model of Electric Genetics is designed to provide modular solutions that are flexible and easily integrated with other tools or analysis pipelines. All products are peer reviewed, incorporate industry standards, embrace open-source bioinformatics and include the option to supplement packaged solutions with professional services, to integrate the solutions into a customer's own environment. These technologies have a dual nature. On the one hand, there is the scientific nature of the process and product, the core of which is gene expression. On the other hand, there are information and communication technologies that include the software, whose design and development depends on the science and the product to be delivered. Electric Genetics attracted a R10 million cash injection from Bioventures, South Africa's only biotechnology venture capital fund, with a total investment in the sector of R38 million.

SANBI and Electric Genetics share physical resources (such as high-capacity computers) as well as staff who provide centralised services (such as system administration). The two organisations have created a fast, open-source development process through which tools are designed and rapidly prototyped for SANBI scientists and their research projects. Participation in the open-source movement is important for both. It establishes standards by providing a type of peer-review mechanism since everyone has access to a concept or product, and users have input into its further development.

The creation of the Human Expressed Gene network was also specifically shaped by grant requirements. Electric Genetics and SANBI were previously co-recipients of an Innovation Fund award of R4.7 million and operated in a symbiotic relationship based on the need to commercialise academic research and develop appropriate technologies. Funding accessed from the Wellcome Trust required a partnership between SANBI and scientists in the United Kingdom. The relationship which now exists with the European Bioinformatics Institute (EBI)/Sanger Institute's Ensembl project grew, in part, out of this requirement – but equally out of commitment to the open-source movement.

The contract with the Wellcome Trust is relatively non-prescriptive and covers only delivery and budget, but the Sanger Institute itself provides an important link. It is responsible, jointly with the EBI, for the Ensembl Genome server project. The EBI, situated at the Wellcome Trust Genome Campus, is a non-profit research organisation that forms part of the European Molecular Biology Laboratory. The mission of the EBI is to ensure that the growing body of information from molecular biology and genome research is freely accessible to the scientific community. Software developers from universities and major pharmaceutical companies have begun participating in open-source development with the Ensembl team to speed up the development of software. An example of such collaboration is the contribution of SANBI and Electric Genetics to the development, analysis and distribution of the database known as the STACK Human Gene Index.

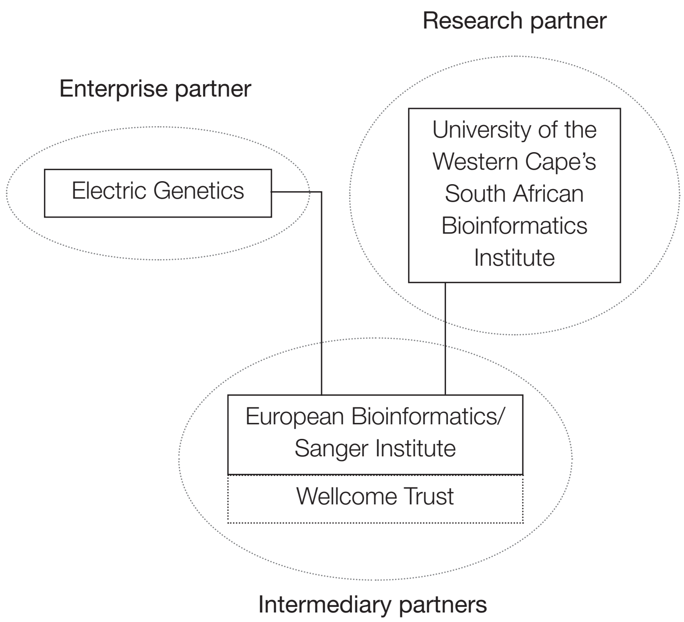
The establishment and growth of the bioinformatics network depended heavily on individual scientists with experience of working overseas who instigated the research and drew in colleagues and collaborators as required. The initial research on gene expression was made possible through a relationship established by the director of SANBI, with the Department of Energy in the USA. He was also co-founder of Electric Genetics, the spin-off company. The Department of Energy funding has been described as 'seed funding', the Innovation Fund grant as 'fertiliser', and the Human Expressed Gene and Disease project supported by the Wellcome Trust as 'serious planting'.

The 'academic way'

In South Africa, higher education institutions and science council laboratories are the primary sources of innovation in the development of new bioinformatic technologies. Knowledge production and transfer in this network thus largely follow established scientific procedures, or as one of the higher education partners explained, the network is structured according to 'the academic way'. SANBI places great emphasis on peer-review processes, particularly in the form of academic publications and presentations at academic seminars and conferences. This emphasis arises in part from the need for SANBI to raise its research profile and establish its credibility in the scientific community, nationally and globally, but equally, from the commitment to open-source arrangements.

An interesting feature of this network is the involvement of scientists on an individual rather than an organisational basis, drawing on pre-existing research relationships around gene expression. For example a professor of National Health and Life Sciences from England was drawn in as an occasional advisor on an individual basis, given her expertise in molecular genetics and prior interactions with SANBI. The formal structure of the network is thus relatively simple (see Figure 2.4). The Wellcome Trust acts as a non-profit intermediary organisation, promoting research and innovation internationally. Because of its location in the UK, and its primarily funding interests, it is not an active intermediary partner. Financial flows move from the Wellcome Trust and the Innovation Fund to SANBI at the academic node, and hence to the commercial node, through SANBI's subcontracting of Electric Genetics as industrial partner. Flows of knowledge are bi-directional – between SANBI and its academic partners, on the one hand, and between SANBI and Electric Genetics, on the other. SANBI researchers are involved in both basic and applied research: in general, SANBI is the primary supplier of research and knowledge and Electric Genetics the main provider of product development and market information. Thus, in many senses, SANBI stands firmly at the heart of the network, with the British academic partners at the one end and the enterprise partner, Electric Genetics, at the other.

Figure 2.4 The bioinformatics network



Informal and flexible operations
The structure of the network is highly flexible and operates largely through informal processes. On a day-to-day level, there is ad hoc interaction supplemented by formal interaction. For example, the director of SANBI serves as the chairperson of the Scientific Advisory Board of Electric Genetics. Although there is a formal contract that regulates relations between SANBI and Electric Genetics, the subcontracting arrangement is facilitated by both these formal and informal interactions. There is also a contractual agreement between the University of the Western Cape (UWC) and Electric Genetics that governs the interaction between the parties at a senior level.

Some degree of hierarchy and asymmetry in decision-making does exist. The two principal investigators make decisions jointly. The British professor is responsible for overall grant management because of his location and his relationship with the Wellcome Trust, and the director of SANBI makes decisions about the content of the research. No formal monitoring or review mechanisms have been specified. Instead, the respondents suggested, the academics are under pressure to deliver on time and provide quality work since they are paid up front and the entire relationship is based on trust.

Knowledge transfers within this network are mostly formal, embodied in the product developed jointly by SANBI, Electric Genetics, the Wellcome Trust/Sanger Institute (WTSI) and the EBI, although some are tacit, in the form of intellectual capital transferred during informal interactions. Since SANBI researchers use the software produced by Electric Genetics, a constant inter-organisational exchange of tacit knowledge is necessary to develop new products and to extend existing products. Proximity is a surprisingly important issue, given prevailing assumptions about globalisation and the role of information technologies in overcoming spatial constraints. In this project, there are two physical sites in which individuals and organisations operate in close geographical proximity that facilitates knowledge exchange – one in Cape Town where SANBI and Electric Genetics are co-located, and one in Cambridgeshire where the WTSI and the EBI are co-located. There is also the 'intellectual proximity' of a close-knit circle of researchers whose inter-personal relationships enable high quality interaction to occur despite the distance between the countries and the relatively impersonal nature of computer-based communication.

One area of tension relates to the existence of conflicting goals around the creation and diffusion of knowledge. Academic research is said to be curiosity-driven while research for commercial application is said to be design-driven. Although the experience of SANBI and Electric Genetics shows that this distinction cannot be made in an absolute way, there remains some conflict between the goals and imperatives of the two organisations. Open-source arrangements have distinct disadvantages as well as advantages. They keep a company on its toes, ensure peer review of the company's work, and guarantee that it is on track scientifically. A disadvantage in this case is that rival companies could use open-source core offerings to develop a product that would erode Electric Genetics' market share. Despite these tensions, it remains important for companies like Electric Genetics to participate in the open-source community. The nature of its products requires that the concept be accepted by the scientific community before commercial application or development can take place.

Comparing structure and dynamics

The network imperative in biotechnology

All four networks are characterised by their multi-disciplinary nature and their reliance on both fundamental and applied research. The sheer scale of the demands associated with the development of a commercially viable biotechnology explains why a single organisation can hardly manage or perform directly all the activities involved. All the respondents recognised that strategic alliances through industrial networks represent an efficient response to these challenges. Hence, the establishment of networks reflects an attempt to internalise the problems of effective knowledge transfer. In so far as the capabilities of an industry are based on the capacities of those with whom they collaborate, network relations raise the price of admission to a field. The case of small forestry companies in relation to the tree protection network is a case in point. Product and process innovations are becoming increasingly dependent on complex organisational matrices. The successful commercialisation of the technologies involved in these networks is beyond the capacity and resources of any individual partner.

Funding criteria, the institutional missions of the higher education institutions, and a desire to enhance particular specialities encouraged academics to undertake collaborative research to address the needs of industry for cost-effective and value-added production and service delivery. The high costs of R&D, the importance of innovation to competitiveness and efficiency, and statutory obligations were the primary motivators for industry and intermediaries to enter into network relations.

Shifting network demands and governance structures

Network demands and governance structures change during the stages of the R&D process. All four networks discussed here are still in a relatively embryonic stage of development and, with the exception of the bioinformatics network, have not yet reached the stage of full-scale commercialisation. The mycorrhizal network is perhaps the least prepared for the rigours of commercialisation. This is reflected in the greater insularity of its design: the intermediary and industry nodes in this network are underdeveloped. Knowledge flows, technology transfer, and network governance are all tied to Amphigro's internal make-up and functioning as a largely self-contained entity within the higher education sector. The water membrane network, by contrast, is on the brink of commercialisation and this is reflected in the consolidation of its industry node. Unlike the other three networks, the mycorrhizal network is also relatively inflexible with regard to its capacity to change rapidly in response to changes in its environment. The bioinformatics and tree-protection networks, for example, are able to draw on various sources of expertise and infrastructure to achieve their changing goals. For the membrane and mycorrhizal networks, the industry partners are still primarily a test bed for expanded versions of laboratory-scale technologies. They provide the facilities to test and 'accredit' the technologies and, depending on the success of field trials, will eventually become the 'clients' of a commercialised joint venture.

Given the vital role of the leading individuals or academic champions in all four networks and the importance most of these networks attach to commercialisation as the final objective, emergent network dynamics are heading inexorably in a more formal direction. Although there are steering committees to oversee the functions of all four networks, personal relationships remain vitally important in their management and co-ordination. These relationships are, however, increasingly being supplanted and augmented by more formal mechanisms as the networks enter the commercialisation stage. The membrane and mycorrhizal networks, in particular, are poised to enter the commercial domain and this requires decisive organisational changes, with a greater reliance on formal contracts.

The nature of competition in the agricultural and pharmaceutical sectors is a significant factor in the structuring of the mycorrhizal and bioinformatics networks. The industry partners are in a sense compelled to enter into partnerships with higher education institutions in an effort to make up for the historically low investments in, and increasingly high costs of, in-house R&D. While the industry partner in the membrane network is a publicly funded body, financial pressures and statutory duties have generated a quasi-competitive environment within the water industry. The pre-competitive nature of the tree-protection network distinguishes it from the other networks in this respect. It provides solutions to tree-growth problems that all forestry companies can exploit to their advantage: maximising the economic potential of a non-expanding asset (exotic plantations) for the benefit of the forestry industry as a whole.

Differences between the networks in terms of proximity to the commercialisation stage are also reflected in the functions and relative importance of the intermediary node. The membrane network will remain dependent on co-ordination and funding from the WRC until the joint venture with Amatola Water takes off. The role of the WRC is then likely to change from funder and network champion to marketing agent and sectoral intermediary proper. The spin-off company in the bioinformatics network has to some extent obviated the need for a distinct, active intermediary as the higher education partners interact directly with the industry partners. The role of the intermediary is least developed in the mycorrhizal and tree-protection networks. As these two networks proceed along a path to commercialisation it is likely that their reliance on sectoral intermediaries such as Forestry SA and Chicory SA will increase. Direct relationships with industry partners are also likely to be strengthened in the process.

Knowledge transfer, collaboration and trust

Trust and reciprocity are revealed as vital preconditions for effective collaboration in all four networks. The division of labour is also largely consensual and mutually beneficial.

Although the respondents described the relationships in positive terms, there are underlying tensions and strains within all the networks. These revolve primarily around the different institutional priorities and 'cultures' that characterise the organisations at the different nodes, although there was strong awareness of the benefits that could be derived if these tensions were effectively managed. This is perhaps best exemplified by the discord and tension surrounding intellectual property rights and organisational structures in some of the cases. The early stages of collaborative R&D were characterised by the virtual absence of either conflict or asymmetries in control. Role differentiation was simple: universities did the research, and industry did the development. With the move towards commercialisation, this division of labour and the established partnership routines come under increasing pressure.

With the exception of the (pre-competitive) tree-protection network, tacit knowledge transfers were central to the operation of these networks. Relatively well-developed formal and informal channels for the exchange of tacit and codified knowledge characterise all four networks. Organisations at the intermediary node played a vital (albeit varying) role in preventing the duplication of research, formalising network relations, ensuring that the priorities of the parties are addressed, and that research is on track. Through their emphasis on capacity building, funding criteria set by intermediary partners has also influenced the distribution of power and rewards.

The shift towards commercialisation has also exposed an extensive reliance on government funding, as well as the inability of existing institutional arrangements to guarantee optimal benefits from expanding collaborative relationships. Chances of commercial success are likely to be significantly enhanced by more effective business incubation. Internationally, incubation is an effective means of sustaining the interaction between higher education and industry. Incubators create an environment favourable for the development, nurturing and growth of new companies and entrepreneurial acumen. Biotechnology companies, in particular, are more likely to succeed if they have emerged from an incubator-like environment. Although the South African government has established BRICs to address the need for incubators and greater inter-organisational collaboration in the biotechnology sector, it is still too early to draw any meaningful conclusions.

Serving the needs and interests of each node

Benefits and outcomes of the network

In this section we will consider the ways in which the partners at each node benefit from the co-operative relationships that constitute the networks. To this end, we will highlight the ways in which knowledge transfers serve the needs and interests of the collaborating parties by generating both tangible and intangible benefits and outcomes.

In addition to the more obvious financial and economic gains, broader social and scientific benefits can also be derived. Access to funding is often dependent on the delivery of specified outcomes. The Innovation Fund, for example, gives preference to projects with the potential to improve efficiency, create employment, attract capital investments, stimulate exports, and promote import substitution. For industry, the principal advantages of partnerships are higher levels of competitiveness, a strengthening of their capacity to identify, absorb and exploit knowledge, and an increase in the rate of product and process innovation. Some of the benefits derived by universities and technikons include funding for basic research, practical training for post-graduate students, the cost-savings of collaborative research, access to government funding, the creation of new knowledge and the refinement of research methodologies, commercial and developmental opportunities inherent in innovative projects, and the acquisition of expertise in technology development and commercialisation.

The water membrane network
For the academics involved in the membrane network, the primary outcome is a commercially viable filtration system. Publishing research papers and attending conferences are secondary to the commercialisation process. Economic benefits in the form of increased competitiveness, financial rewards and joint ventures are also in some respects subservient to the primary goal of contributing to socio-economic development (especially in the rural areas). A flow of funds from the joint venture into the higher education institutions will stimulate further research, thereby contributing towards the creation of further possibilities for commercialisation. It is believed that by maintaining its links with the higher education research entity, the joint venture will ensure that it does not become a 'one-hit wonder', but rather, the core for the further development of South African membrane technologies.

The higher education respondents suggested that network relations constitute an effective means of knowledge transfer, especially for historically disadvantaged institutions, and that they drastically increase the pace of innovation and commercialisation. Network relations have facilitated greater interaction between historically white and black institutions, and between institutions and the community. A significant enhancement of student skills was believed to have resulted, through their regular interaction with industry partners, enhancing their understanding of commercial enterprise and improving their prospects of finding suitable employment.

Not only do these new water purification technologies improve access to safe water, their successful development and application also raise the national profile of the WRC. For Amatola Water, links with higher education allow it to employ fewer R&D staff and encourage greater involvement in skills transfer and socio-economic upliftment. The early stages of R&D, according to one of its directors, are, 'too risky for Amatola Water to invest in'. Since Amatola Water plays an active part in the testing and fine-tuning of the capillary ultra-filtration system, its staff members are acquiring valuable skills and expertise in the technology and passing the practical knowledge gained in field trials on to the researchers.

According to all, the capillary ultra-filtration system has tremendous industrial potential. Although the system is still more expensive than conventional filtration systems, it does not require the continuous presence of operators, can be set up very quickly, is reliable and easy to operate, and produces water of a consistently high quality. The elimination of operators is regarded as particularly advantageous for Amatola Water: not only does it reduce staff and training costs, but also overcomes the problems experienced in monitoring the service of operators. As one of the project leaders noted, with the capillary ultra-filtration system, 'the water is as good as the membrane is and has nothing to do with the skills of the operators'.

The mycorrhizal network
Being in effect both lead enterprise and research entity, Amphigro obviously benefits the most from the mycorrhizal network. Immediate knowledge benefits comprise the building of intellectual property, as the outcome of AMF research and the related development

of new processes and products. These will now provide a platform for the large-scale commercial production of successfully isolated and tested inoculants. Industry partners may benefit directly from positive outcomes of field tests. The successes of these evaluation trials are likely to encourage confidence in the product, thereby establishing a future market for Amphigro.

No Amphigro-authored publications have yet been forthcoming, the reason being the delicate nature of intellectual property ownership issues. Consortium members claimed that it is in Amphigro's best interests to err on the side of caution by not publishing any R&D findings. However, some papers on the general science of inoculum production have been published in accredited scientific journals.

The main benefit to the university base concerns the education, development and empowerment of post-graduate students in a new research field of mychorrhizal science. Potential employment opportunities for such students are improved as more enterprises become established in this field. These human resource development processes are viewed as contributing to the socio-economic development of the country. Unanticipated outcomes have also emerged for individual researchers during the course of the project, relating primarily to dimensions of personal growth and development, such as approaches to problem-solving.

The tree-protection network

The TPCP provides four main services to its clients in the forestry industry. Firstly, it maintains a diagnostic laboratory, which uses state-of-the-art equipment and techniques to isolate pathogens and test them for their ability to cause disease. The laboratory also maintains an extensive culture collection, including tree pathogens collected in South Africa over a 15-year period. Secondly, the TPCP conducts research on diseases of pine, eucalyptus and wattle trees. Thirdly, it monitors disease development in plantations, in permanent sampling plots and through countrywide surveys to gain a perspective of their relative importance. Fourthly, the TPCP runs an extension service through which field foresters are informed about strategies for reducing the impact of diseases, and forestry students are educated about tree pathology (www.up.ac.za/fabi).

Pretoria University derives considerable benefits from this network in the form of the training of post-graduate students and the publication of cutting-edge research in internationally accredited journals. FABI's products, then, are new knowledge and its application on the one hand, and trained scientists on the other. The two meet in a conception of education as the main output – knowledge being produced by and purveyed through FABI's students and staff.

The benefits for industry flowing from the advances in forestry research are significant. First, through tree breeding, volume production has increased by 10 to 30 per cent, and through smaller branch sizes there has been a 10 per cent reduction in pruning costs. Spectacular improvements through the cloning of genotypes have brought about a 46 per cent improvement in the average volume production of E-grandis clones, and 25 to 70 per cent less splitting of harvested timber. Second, South African silvicultural research has had a major impact on forest science worldwide. New procedures have been developed regarding pruning, planting distances between trees, thinning, periods between harvesting, and other features. As a result, plantation-management practices have been greatly improved (www.dwaf.gov.za).

The bioinformatics network

Electric Genetics is the first bioinformatics company in South Africa. The University of the Western Cape is a 1 per cent shareholder in the company and receives royalties for products developed out of the partnership between the company and SANBI. The university is reported to have received close to R1.5 million from Electric Genetics (*Business Day*, 7 May 2003). The challenge for UWC and SANBI, now that the bioinformatics research foundations are in place, is to realise the potential of the software, tools and algorithms developed, and to become the resource of choice. By increasing its research output, UWC can consolidate its position and begin to challenge other universities in the fields of biotechnology and bioinformatics. A further benefit is that, while the products are sold to pharmaceutical, biotechnology and genomics companies around the world, they are provided free to academic research groups.

Electric Genetics commercialises a range of products and services. It played a key role in the development and distribution of stackPACK, the most widely used transcript reconstruction and management tool in the market. An output of the project with the WTSI and the EBI is EnsMart, a data-retrieval tool that generates lists of biological objects (such as genes) from data held in the Ensembl database. EnsMart is a powerful data-mining tool for retrieving customised data sets from annotated genomes, integrating data from various worldwide data sources. It provides a generic data-warehousing solution for fast and flexible querying of large biological data sets and integration with third party data and tools. The company's latest offering, eVoke, an expression ontology toolkit, was reportedly becoming a global 'industry standard' for describing gene expression states (EBI press release, 14 August 2003).

For Electric Genetics, strategic collaboration makes good business sense. Providing products free of charge to researchers benefits the company since academics provide feedback by sharing their data and annotations. SANBI benefits by involving researchers in defining best practice for the scientific community, thereby allowing it to develop more accurate formats. The bioinformatics network improves the ability of the research community to overcome problems of scale, the comparative lack of funding opportunities in South Africa, and helps to prevent unnecessary duplication of costly research.

A balance of tangible and intangible benefits

There was general consensus among the respondents that an equitable distribution of benefits and costs is vital to the long-term sustainability of a network. The benefits derived by the parties are both tangible and intangible. Strategic alliances allow intermediary organisations and higher education institutions to carry out their institutional missions, raise their profile, and improve their financial, organisational and human resource capacities. Most of the higher education respondents viewed the benefits of networking not only in narrow individualistic or financial terms, but also in a wider social and economic sense.

Although the balance varies, it tends to tip towards tangible benefits as the process of commercialisation proceeds. However, many of the anticipated tangible outcomes of networking are yet to be realised. For instance, key outputs such as the creation of SMMEs, technology licence agreements, patents, and the training of a new cadre of scientists and engineers are yet to be realised on a significant scale. This is in large measure due to cost considerations and the embryonic commercial application of the technologies at the heart of these networks. It is therefore not surprising that the bioinformatics network, with the most developed commercialisation process, is associated with the most extensive outcomes. The membrane and mycorrhizal networks, by contrast, are still in the process of developing a viable product that can be successfully marketed. In the membrane and mycorrhizal networks, research findings are regarded as trade secrets and publication is therefore discouraged. In the tree protection and bioinformatics networks, by contrast, publication is encouraged due respectively to pre-competitive and open-source environments.

Limitations and future possibilities

Collaborative relations between industry and higher education face numerous obstacles, especially in the field of biotechnology where a rapid rate of innovation is the key to economic success and a defining feature of competition. The concern here is with the factors that facilitate or constrain the development of network relations, and the incentives for maintaining and extending the networks. We have already hinted at the many possibilities of network relations in the discussion of the benefits derived from collaboration, and have mentioned some limitations in the discussion of network dynamics. Here we elaborate some of the challenges to greater collaboration in South Africa that are highlighted by the four biotechnology networks.

Government incentivisation

With the growing importance of innovation as a determinant of competitiveness, government policies to promote R&D at the enterprise level, which were previously limited, are becoming more significant. Currently, the national innovation policy framework has done much to encourage the development of collaborative relations between industry and higher education institutions. The DTI and DST – through the vehicles of THRIP, the Innovation Fund, the National Research Foundation and the National Advisory Council on Innovation – have played a pivotal role in laying the basis for greater interaction. Perhaps the most significant change ushered in by the new policy framework is the encouragement of a 'culture of co-operation and entrepreneurship'.

Earlier rounds of Innovation Fund funding were mostly focused on basic research, to the detriment of commercialisation and technology transfer. This resulted in state-funded research making a negligible contribution towards the establishment of viable biotechnology companies. Subsequent calls for funding are more specific about the commercial exploitation of research results. However, only a small percentage of biotechnology projects are initiated in private sector laboratories. Most of the private companies that participate in partnerships formed through the Innovation Fund are receivers of technology developed in university or science council laboratories – as the mychorrhizal and bioinformatics cases illustrate.

A shortcoming of the present funding formula, highlighted by the membrane network, is the inability of research units without an established track record to access funds for smaller projects aimed at developing prototypes that may attract interest from industry. Historical legacies in the higher education field pose significant challenges to the state's funding policies. Institutions that possessed the necessary infrastructure and resources were quick to exploit the opportunities presented, but by contrast, those historically-disadvantaged institutions that lack the capacity for networking or fail to receive the necessary support from their administrations, struggle to initiate and sustain strategic alliances with industry.

A second shortcoming relates to the requirements of commercialisation. In the mychorrhizal network, for instance, the ability to produce and market a fully substantiated product on a large scale is still some way off. The time taken up by certain trials can stretch over several years, depending on which plants are involved and the range of variables that have to be accounted for. In view of these realities, enterprise members have been attempting to access bridging funds, but with little success. Attempts at securing venture capital have been frustrated by the fact that very little product awareness exists in the market place generally, and within the agricultural sector specifically.

A related difficulty experienced in the bioinformatics network is that government funding time frames are short-term: the DST, for example, works on three-year cycles, which is too short a time horizon to move to commercialisation. External funding was seen in general as inconsistent and unpredictable, which could jeopardise the network. Medium- to long-term cycles that would enable and facilitate the building of institutional capacity and scientific infrastructure are required.

Biotechnology infrastructure in a newly industrialising country

Globally, concerns are being expressed that insufficient attention has been paid to promoting research that focuses on the problems prevalent in developing countries. Investment in genomics and genomic technology transfer geared towards the creation of the conditions necessary for genomic innovation, and ultimately to improved outcomes in areas such as health and the environment, are lagging behind in developing countries. Companies like Electric Genetics, which do such research, may be at a disadvantage relative to their competitors because they are geographically remote from the locus of innovation and cutting-edge science, and in addition the customer and scientific bases in South Africa are both currently very small.

The four network cases discussed here provide evidence of research that is oriented to the developmental needs of South Africa. Besides the economic pressures of competition, the membrane network is driven by the developmental mandate bestowed on the water industry to increase both the scope and affordability of service provision. The tree-protection network is also mandated to eradicate the legacy of apartheid through its small growers development programme. The other two networks are more explicitly geared towards commercial benefits, but both have potential long-term social impact.

Biotechnology of the kind engaged with by networks like the TPCP and bioinformatics needs a solid physical and social infrastructure to survive and thrive. SANBI is developing a range of innovative bioinformatic technologies, but the benefit to local industries, such as pharmaceuticals, is limited. This is due largely to a restricted infrastructural and R&D capacity, for instance, limitations in South Africa's communications infrastructure is a constraint for bioinformatics research, which requires the importation of large databases, and sophisticated software development requires supercomputing capabilities that are currently insufficient. The National Bioinformatics Network has been established to facilitate the development of such capacity and to undertake negotiations with national players such as the Department of Communications and Telkom.

Biotechnology such as described here needs greater infrastructural investment and skills development in order to take root in South Africa. In the absence of a vibrant biotechnology industry in the country, the TPCP, for instance, is likely to generate a body of knowledge that will either leave the country or mutate into other kinds of competence, with biotechnologists becoming managers or moving sideways into other disciplines. The worldwide shortage of bioinformaticists is also evident. Estimates suggest that it takes about ten years to train a high-level bioinformatics expert, which means that South Africa will have to attract experts from international institutions to form a core of expertise. South African institutions will therefore have to provide competitive salaries and working conditions, recognising that bioinformatics specialists are among the best-paid academics in the world. If capacity and infrastructural shortcomings in South Africa are not addressed, the country's competitiveness in biotechnology could be severely constrained.

Ownership of intellectual property rights

It is evident above all that the ownership of intellectual property rights generated from industry-funded research can lead to significant tensions within networks. Industry wants to see a return on its investment, while the scientific discoveries made at universities and technikons are only possible because of prior investments by these institutions in basic research and skills development. Private companies regard information as a strategic resource and tend to guard it closely, imposing confidentiality agreements. Rapid developments in biotechnology have placed enormous pressure on academics to publish their research findings for fear that someone else might do so before them. Such dynamics are evident in varying degrees in the four networks.

Many academics have little experience in dealing with legal issues, and often lack support, since most South African universities and technikons do not have intellectual property offices or policy guidelines. In the mychorrhizal network for instance, due to the unique circumstances that existed with regard to the individuals in the group and the need to safeguard intellectual property and financial autonomy, the three university-based members negotiated separate contracts, over and above their original employment contracts, to protect more effectively their ownership of the intellectual property rights that flow from the project. In retrospect, this proved a strategic move since institutions have become more restrictive about ownership now that there is formal policy and procedure with which they have to comply.

Changes in higher education institutions

It is evident that the management and administration policies and structures at an institution are significant, and that there are differences between universities and technikons, and between historically advantaged and disadvantaged institutions. For instance, in the membrane network, technikon researchers reported management's tendency to defend existing powers and privileges, and to block any initiatives aimed at changing the status quo. There is no collective vision to drive the institution in the direction of sustained partnerships with industry and the public sector. The institution's internal allocation of financial resources was seen as inequitable and inefficient and not supportive of innovative work. In contrast, inter-disciplinary co-operation at Stellenbosch University is actively promoted and highly advanced.

There is a real threat, however, that attempts to close the innovation gap primarily by connecting the higher education sector more closely with the market may drive the academic system towards short-term, incremental problem-solving and consulting. For instance, the extension service of the tree protection network does not have the capacity to meet the increasing demand for its services in the field. By expanding this component of its work, FABI runs the risk of detracting from its core focus on the education and training of students. Part of the fine balance at the heart of the networks thus involves maintaining equilibrium between research and work with industry, so that the higher education research system remains viable in the long term.

Dynamics of competition and co-operation

It could be argued that the reliance on government funding in the networks described here is now too extensive. Industry partners tend to have a narrow conception of collaborative R&D – it should provide immediate financial benefits and/or solve specific problems. In three of the four networks, the industry partners tended to play a largely passive role in the development of new technologies and in knowledge transfers, essentially providing testing facilities and market opportunities for selected products. These networks are still in the early stages of development and motivated primarily by cost-savings and the spreading of risks associated with innovation. Ways need to be found to encourage the business sector to make a much more substantial contribution.

The establishment and maintenance of collaborative relations depend ultimately on an institution's capacity to satisfy the needs of industry partners. In this regard, the contrast between the Umgeni and Amatola water boards in the membrane network is instructive. While Umgeni Water readily provided the researchers with access to its facilities, it showed little interest in the technology or in the development of knowledge-intensive network relations. This reluctance stems from the fact that such collaboration would have made it very difficult to justify the costs of its R&D staff. A pressing need for greater volumes of safe drinking water in peri-urban areas encouraged Amatola Water to collaborate actively in much more intense processes of knowledge transfer and granted it a direct stake in the network's success.

The dynamics of competition in a particular product market or industrial sector are thus closely linked to the dynamics of co-operation found in that market or sector. Competition provides the fundamental impetus for collaboration and plays an important role in shaping the scope, structure and content of strategic alliances, and in establishing the limits and possibilities of network relations.

The most formidable obstacle to the expansion of all four networks is thus the relatively small biotechnology industry and market in South Africa. This is compounded by the difficulties experienced in gaining a foothold in a highly competitive and integrated global industry. The long-term success of the bioinformatics and mycorrhizal networks, for example, are directly dependent on the expansion of the local biotechnology sector. That, in turn, depends on the ability of both government and industry to encourage and nurture biotechnology start-up firms, to enlarge the institutional and infrastructural framework of the biotechnology industry, to create and retain the necessary human resources, and to develop an effective venture capital market.

CHAPTER 3

Information and communication technology networks: leading or following the economic sector?

Andrew Paterson

Information and communication technologies in context

The diffusion of information and communication technologies (ICT) has occurred concurrently with and in support of a series of global structural changes.[1] Even though there is divided opinion on the extent of the contribution of ICT to economic growth, the role of ICT in enterprise competitiveness across many economic sectors is rarely seriously contested. The ICT sector is also of critical importance in its own right as the source of goods and services that enable other economic activities. Thus an interactive cycle of demand and supply is established both between the ICT sector and ICT-user sectors, as well as within the ICT sector itself.

The ICT sector is a demonstrably dynamic and competitive environment within which innovation – arising from the application of human ingenuity to technological plasticity – is highly valued. In the enterprise environment, such ingenuity is seldom applied by isolated individuals. Rather, innovations evolve from and are sustained by networks of persons linked through communities of practice, or by networks of enterprises with shared goals. International data from the early 1990s shows that the ICT sector had a significant share of R&D strategic alliances as compared with other sectors (Hagedoorn 1993). These interactions are critical to the contribution of R&D to innovation in the ICT sector, which then diffuses into ICT-user economic sectors.

Defining the field of ICT

Defining the ICT sector is complicated. A useful starting definition understands ICTs as:

> …technologies that facilitate communication and the processing and transmission of information by electronic means. (Marker, McNamara & Wallace 2002)

The new technologies present a theoretical and analytic challenge because of a lack of commonly accepted standards for defining them on a sectoral basis. This is by virtue of the nature of ICT itself, as a group of technologies that are, 'not stable, but in a process of ongoing change' (Selhofer 2000: 512), leading to rapid changes in and blurring of sectoral boundaries. Furthermore, the application of ICT as a general-purpose technology makes it very difficult to define the boundaries of ICT activities on an industry basis.

Nevertheless, for the purpose of this project, a definition has been derived from the version adopted by the South African Isett (Information Systems Electronics and

1 This chapter is based on case studies written by Michael Cosser, Carel Garisch, Rachmat Omar and Gilton Klerck.

Telecommunication Technologies) Sectoral Education and Training Authority (SETA). This definition specifically excludes industries that generate content, but does include technologies that support broadcasting activities. It states that ICT activity is:

> …those business activities which facilitate, by electronic means and associated services and support, the processing, storage, communication, transmission and display of information, and it *excludes* the industries which create the information, the so-called 'content' industries. (Isett SETA Sectoral Skills Plan: 21)

The South African ICT Sector as defined by Isett comprises three distinct, but interlinked sub-sectors: Information Technology, Electronics, and Telecommunications. R&D activity frequently – though not always – involves networking of enterprises across the three sub-sectors.

Economic performance of the South African ICT sector

Performance in relation to other domestic industrial sectors

As has happened elsewhere, the ICT sector in South Africa has been subject to the surges of activity energised by growing investor confidence and the Y2K problem, followed by the sudden reversal of the dot.com crash, coupled with the effects of a global economic slowdown. Despite this volatility, the local sector has shown positive growth, particularly because ICT is an integral component of the financial services, business services, banking, and wholesale and retail sectors where information intensity is high (James, Esselaar & Miller 2001; Hodge and Miller 1997; Nordas 2002). There is evidence to suggest that the sectors specialising in ICT and services have exhibited the strongest growth in investment and input over the last decade (Treasury 2001). The ICT sector was sized at R7 billion in 2000. In terms of industry sector contribution to South Africa's Gross Domestic Product (GDP), it was projected to reach 2.5 per cent for 2002–2003, while sales in the sector were estimated to be 7–8 per cent of GDP (Leadership 2002).

Performance within the South African ICT Sector

The scale of economic activities can be understood with reference to the consumption of ICT goods and services in four sub-markets: software, hardware, IT (information technology) services, and telecommunications.

Software development is limited mainly to local integration of overseas products with nascent indigenous software development capacity, and is visible in internet security, banking systems, and, more recently, in web-based software development (James, Esselaar & Miller 2001: 4).

The market for computer *hardware* in South Africa levelled off after Y2K, and is slowly recovering. It should be noted that South Africa imports most of its hardware, although some assembly is undertaken locally.

IT services in the form of customised application development, consulting, systems implementation and ICT training showed a strong average annual growth rate of 20 per cent from the late 1990s into 2001 (James, Esselaar & Miller 2001: 7). This trend is likely to continue with growing interest in hosting services, web hosting and internet service provider (ISP) services.

The national *telecommunications* market was estimated to be in the region of R48 billion in 2000, with the lion's share being in fixed and mobile connectivity and data services. South Africa's use of the internet made it the fourteenth largest global internet country market (DTI 2004). The sector was subject to significant regulatory and policy changes between 1994 and 2004 (Barendse 2004). However, Gillwald (2003: 23) argues that the statutory protection of Telkom that ended after the former parastatal was privately listed in 2003, had a, 'chilling effect on the growth of this critical sector in the network economy'. Telkom still enjoys monopolistic control of a vertically integrated market and competes downstream in value-added network service (VANS) and the ISP market segments. Telkom can deny rival firms access to its network through delaying or pricing strategies. This has placed constraints on the deployment of alternative cost-competitive technologies such as VSAT (very small aperture technology) and VOIP (voice-over internet protocol).

Apart from fixed line operations – dominated by Telkom with 5.5 million fixed lines currently installed – South Africa has a fast-expanding cell (mobile) phone market, which is the largest GSM (global system for mobile computing) market outside of Europe (DST 1999).

In addition, in the South African *electronics* industry, revenues exceeded R55 billion in 2001 and are set to sustain growth comfortably above the GDP growth rate. Assuming improved regulatory and economic conditions, this sector can look forward to high levels of future activity, based on business from the burgeoning African telecommunications market. Major enterprise players in industrial, power, defence and telecoms electronics include Siemens, Alcatel, Ericsson, Altech, Grintek, Spescom, Tellumat and Marconi (DTI 2004).

International performance

The positive domestic performance of the South African ICT sector is not sustained in export activities. With reference to market size, the country was ranked twenty-third worldwide in total ICT spending in 1999 (US$10 898 million) (Cogburn & Adeya 2002: 20). South African enterprises are becoming market leaders in the pre-payment, revenue management and fraud-prevention systems as well as in the manufacture of set-top boxes, approaching R4 billion in sales. Business services in particular have shown the highest export growth in the 1991–2001 period (TIPS 2003: 12–13). Nevertheless, exports of ICT and communications products are low. Evidence from a census of ICT firms in the Western Cape province bears out this observation, where enterprises indicated that exports represented less than 20 per cent of their income (CITI 2003). South Africa's share of world trade in ICT products, at 0,06 per cent, is very significantly lower than South Africa's average over all product exports of 0,7 per cent (Leadership 2002). This can be attributed in part to the tendency for the ICT sector, in the period after 1994, to focus on supplying a small group of large domestic clients. This may be changing as foreign direct investment flows into the country. According to *Business Map*, '[the] Telecom and IT sectors received by far the highest foreign direct investment compared with other sectors, between 1994 and 2000 estimated at R16 billion' (cited in Nordas 2002: 23).

Prospects for R&D and networked interaction between enterprises in the ICT sector

The ICT sector in South Africa seems to be growing moderately, in synchrony with the financial services industries. So far this growth has been largely based on domestic consumption rather than on exports, and is based mainly in communications and IT services, less in software development, and least in hardware. The sector as a whole is not operating to its potential, which means that R&D activity is in all likelihood not developing as fast as it could or should.

The electronics sub-sector was an extremely important industrial element in the period of apartheid sanctions, supplying the country's telecommunications, broadcasting, manufacturing and defence industries. After 1994, this sub-sector went into decline, outflanked by rapid development of new technologies, and under threat from world-class competition (Isett SETA 2002: 19), with concomitant losses of highly-skilled labour. There are signs that production activity – though not necessarily employment – in this sector is rising.

It must be noted that government is the single biggest spender on ICT – government and parastatal expenditure was estimated to be R10.2 billion in 2002 (*Financial Mail*, 3 May 2003). As a major consumer of ICT products and services, government could spur R&D when it begins allocating more resources to implementing e-government on a large scale.

The shape of ICT industries in relation to the set of case studies

In South Africa – as is the case internationally – ICT represents a relatively complex and diverse domain of economic activity. Brown and Duguid (2002) argue that, in any country, national differences in innovation are strongly related to industrial structures. We may therefore presume that the structure of South Africa's ICT sector will influence local ICT R&D activities.

A brief description of the enterprises in the ICT sub-sectors is useful, so that the set of case studies can be framed within the sector as a whole (Table 3.1).

Table 3.1: Number of organisations, by sub-sector (2002)

Sub-sector	Enterprises		Employees	
	N	%	N	%
IT	5 597	87	133 700	63
Electronics	165	3	58 700	28
Telecommunications	612	10	19 800	9
Total	*6 374*	*100*	*212 200*	*100*

Source: Isett SETA (2002: 3); (AMI, 2002: 14)

As can be seen from Table 3.1, the telecommunications sub-sector contains the smallest proportion of employees. These enterprises are overwhelmingly active in 'television signal distribution' and 'wireless telecommunications (excluding satellite)', with a small pocket of activity in 'cable network services' (see Appendix A). As a result of the long-standing Telkom monopoly, a significant proportion of R&D activities in this South African sub-sector have concentrated on alternative forms of data communication, such as wireless and satellite telecommunications. Two of the case studies selected involve R&D activities in this band of business activity.

The IT sub-sector is by far the largest in terms of enterprise and employee numbers (see Table 3.1). However the size of a sub-sector is not necessarily proportional to its capacity for engaging in R&D networking activities. For example, the overwhelming majority of enterprises in this sub-sector are involved in 'computer related services', 'repair and maintenance', 'rental and leasing' and 'management services'. A number of enterprises are involved in 'customer computer programming services' and 'call centre and customer relationship management system development', which are based mainly on existing technologies and platforms and are unlikely to involve significant R&D (Appendix A). Activities in which higher levels of R&D might be expected, such as 'software publishing' and 'computer systems design' account for a small proportion of the enterprises in the sub-sector. One case selected is involved in this band of activity.

In the electronics sub-sector, the overwhelming majority of enterprises import pre-manufactured IT electronic components (Appendix A). This suggests that, in the main, local R&D-associated networking is at a low level. Notably, there are no enterprises in the electronics sector that are identified as specifically engaging in research and development as their primary activity (Isett SETA 2002). However, some enterprises in this sub-sector may be value-adding through identifying new applications based on pre-manufactured equipment and might therefore be willing to commit resources to R&D. One of the case studies provides such an example.

A key characteristic of the ICT sector is the distribution of enterprise size. The sector is characterised by numerous small organisations, about 80 per cent of which have fewer than five personnel, and 88 per cent fewer than ten (Isett SETA 2002:3) (Appendix B). The HSRC (2003) indicates that in South Africa small and medium enterprises (SMEs) account for 58 per cent of industry partnerships in the ICT sector, which is not on par with their overall share of enterprise numbers. In the set of case studies presented in this chapter, several SMEs are involved.

When occupational structure is broken down to the sub-sectoral level, significant differences between the three sub-sectors with respect to the proportions of high-level skills are revealed: IT 36.7 per cent, telecommunications 16 per cent and electronics 10 per cent (Appendix C). The relatively low proportions of personnel with high level skills such as computing, and of associated professionals and engineers – as opposed to technicians, administrators and managers – suggests that the human capital that is essential for R&D is at a relatively low level in the South African ICT sector. The theme of high-level skills shortages in ICT R&D and the strategies of both enterprises and higher education institutions for acquiring such skills are visible in all of the case studies.

Importantly, however, the case studies analysed here are not claimed to be representative of the distribution of R&D or the configurations of all networks across the three ICT sub-sectors. Indeed, the case studies are located primarily in the telecommunications sub-sector. The 'bias' may be reflective of uneven levels of R&D activity in the ICT sector with a preponderance of work in telecommunications, or it may be that R&D in other ICT sub-sectors is undertaken without involving the higher education sector. Indeed, HSRC research suggests there is a much higher incidence of academics undertaking consultancy research for ICT enterprises than for enterprises in the biotechnology or new materials fields (Kruss 2005). This form of consultancy partnership is usually focused on meeting immediate and applied industry needs rather than resolving the more complex problems that are at the heart of networks. However, the cases do illustrate current cutting-edge practice in collaborative higher education-industry R&D, and in that sense, as they are described in the following section, it will become evident that each illuminates a great deal.

Case study 1: Optical fibre characterisation programme

The first case investigated was a network of participants that supports an optical fibre characterisation research programme. This programme feeds into activities of enterprises in the telecommunications sector in South Africa – more specifically those engaged in the manufacture of optical fibre cables and related products for supply to telecommunications service providers. This activity is based on increased demand for connectivity and bandwidth supply – though currently in a short downswing due to the 'dotcom crash' – arising out of heightened information intensity across a wide range of economic activities on a global scale.

The research programme focuses on measuring the polarisation mode dispersion (PMD) characteristics of optical fibre and optical fibre cables. PMD refers to the fact that light pulses transmitted down optical fibres suffer a degree of distortion, caused by micro-imperfections (such as irregularities or bends) introduced in the cabling during manufacturing, handling and installation. Environmental conditions (for example, temperature and wind pressure) can also produce changes in PMD characteristics of cabling.

Polarisation mode dispersion reduces the speed with which optical fibre cable transmits data. Reduction in data transmission rate is a serious matter, not only because it affects the quality of service, but also because bandwidth is sold in huge volumes and imperfections in cabling result in percentage reduction in transmission revenues over the lifetime of the cabling. It is imperative for enterprises to minimise such losses in a data-transmission market not fully recovered from the dot.com crash which started in 2000, where spare capacity is still available globally, and where investment in infrastructure is low.

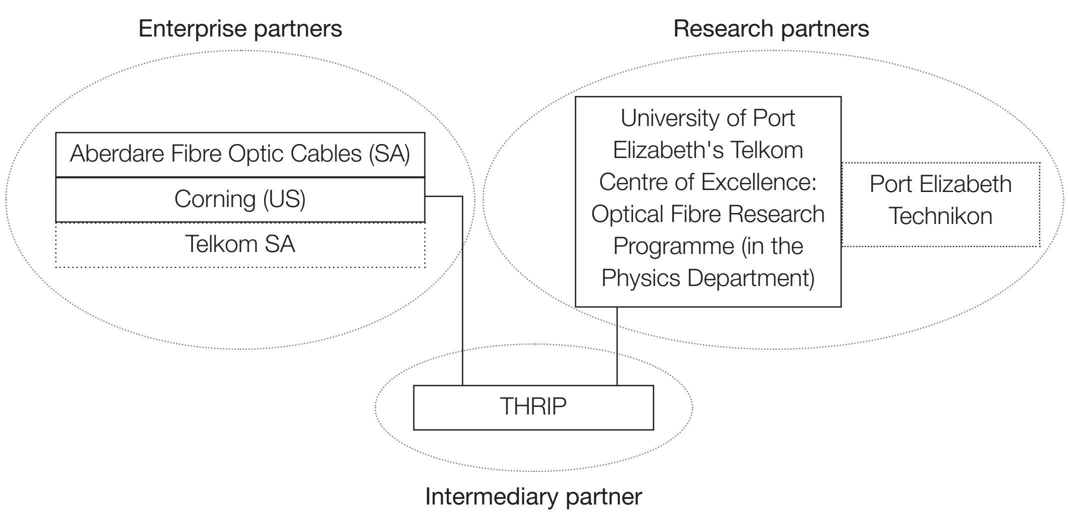
The aim of the research programme is to measure the PMD of the optical fibre cables and also to assess the effect of the different manufacturing stages on PMD.

The product value chain linking Corning, Aberdare and Telkom

As Figure 3.1 reflects, the key corporate players in this research network are:

- Aberdare Cables, a South African fibre optic cable manufacturer;
- Corning, a US-based global optical fibre manufacturer which has part ownership of Aberdare; and
- Telkom South Africa, the major local fixed line telecommunications provider, and a major client of Aberdare Cables.

Figure 3.1 The fibre-optic cables research network



It is not accidental that these three enterprises should be underwriting the research. They are joined together in a series of interactions leading to the delivery of a service in the South African marketplace. The functional links in the chain leading to the provision of data-transmission services imply a common purpose. This series of links can be described as a 'value chain', a construct originating with the work of Porter, according to whom it is possible to divide, 'a company's activities into the technologically and economically distinct activities it performs to do business' (Porter and Millar 1985: 2). These 'value activities' are functionally linked together in a 'chain' that comprehensively captures each activity in the entire business model, as summed up in Figure 3.1.

As explained by Porter and Millar (1985: 2), a business is profitable if the value it creates exceeds the cost of performing the value activities. In a competitive market environment it is necessary for an enterprise to, 'perform these activities at a lower cost or perform them in a way that leads to differentiation and a premium price' (Porter and Millar 1985: 2). The value chain for an enterprise in a particular industry is, 'embedded in a larger stream of activities…[termed] the "value system"' (Porter and Miller 1985: 2). The value chain in this network is that the manufacture of optical fibre is followed by bundling into cable, installation and eventually culminates in the provision of data transmission. This value chain – linking Aberdare, Corning and Telkom – stands in competition with other similar value systems potentially leading to the provision of the same service.

Over and above competition *within* the wired telecommunications sub-sector, competition for data transmission business is sharpened by potential competition for the same business from alternative data transmission media such as wireless and satellite. The second case study focuses on such an alternative technology for broad band data transmission, and provides a useful counterpoint.

The role of research in the strategic positioning of Corning and Aberdare

Although Aberdare and Corning are represented as two enterprises, in reality they are very closely linked. Between 1997 – when restrictive legislation on optical fibre importing fell away – and 1999, Corning become the primary supplier to Aberdare. In 2000 Corning signed an agreement with Aberdare in terms of which it would acquire a 50 per cent stake in Aberdare by 2003. The move from a supply alliance to an equity partnership can be read as a strategy to build a base from which three markets could be attacked: the South African private network market, the South African public telecommunications market and the relatively untapped African market.

Firstly, as regards the South African market: the alliance between Corning and Aberdare preceded the lapse in 2002 of legislation protecting Telkom as the only national wired service provider. A range of consortia were ready to bid for the second national network operator's licence, which is as yet only partially resolved in 2005, because the equity partners for only 49 per cent of the second national operator are secured. Major participants in the second national operator bid are the South African corporates, Eskom and Transtel. Eskom, the national power utility, has created an optical fibre infrastructure based on its power grid, and the transport conglomerate Transtel has a strong communications infrastructure built on its rail network. Eskom and Transtel thus can offer a second longhaul telecommunications backbone to compete with Telkom.

Aberdare, which already supplies Telkom, has extended its client base to include Eskom and Transtel. Furthermore, Aberdare understands that competition between two national fixed line service providers will fuel the South African fibre optic market, with broadband access at the heart of the competition. Each service provider will need to invest in optical fibre backbone as well as in laying cabled access to consumers. Clearly Aberdare and Corning have positioned themselves strategically for the conclusion of the second network operator licensing process.

Second, opportunities for business in Africa are growing as the telecommunications market begins to open up across the continent. This may be speeded up by the emphasis given to communications and information technologies as part of the New Plan for African Development (NEPAD) process. By securing a partnership in Aberdare, Corning has succeeded in finding a foothold from which to launch into the growing African market.

It is significant that although Corning did specify the PMD characteristics of its optical fibre, and also applied a conversion factor to estimate its PMD characteristics after the cabling process, the precise effects of cabling on PMD were not empirically investigated and were therefore not known before the characterisation research programme was launched. The reasons for investing in measurement in PMD may, however, lie in the events described below.

As the optical fibre manufacture industry has evolved, competing patents have been registered (Soares 1994). Following the lapse of an earlier patent for optical fibre manufacture, Corning, as a market leader, developed a new 'outside vapour deposition' process (OVD), and subsequently, its Japanese competitors developed a competing but very similar process – 'vapour axial depostion' (VAD). These processes are so similar that patent authorities in Western Europe and North America refused to allow fibre manufactured according to VAD technology to be sold in those regions. However, the Japanese-made VAD fibre is sold in Africa, Asia, South America and the former Russian federation. Without enjoying the protection of its product in these contexts, Corning is forced to add value. Research can provide such an advantage, which differentiates its own product from its VAD competitor in the African market, in the form of an instrument that can measure PMD and demonstrate OVD cable quality standards. In the future it is likely that specifying the PMD rates on cable will become a standard practice across the optical fibre cable industry. While Aberdare has the opportunity, it can enjoy a competitive advantage and reinforce its branding as a quality product with reference to PMD measurements.

Locally, Aberdare (SA) has a small group of technical experts who conduct product testing and modification, but it does not have staff dedicated to R&D. It depends in part on Corning, which spends approximately eight per cent of its total revenue on research and development – a high proportion by industry standards. In terms of their equity agreement, Aberdare pays a turnover-based technical aid fee to Corning, which provides technical support for Aberdare's technical staff.

Finally, Corning and Aberdare clearly see advantages in consolidating a research facility on the African continent. The same PMD characterisation research can feed data into project work aimed at the development of cost-effective and durable solutions for developing countries seeking access to the technology.

Establishment of the optical fibre programme and network structure

Polarisation mode dispersion was a very new concept in the telecommunications field in South Africa when Aberdare and Corning approached the University of Port Elizabeth (UPE) Department of Physics to set up an optical fibre characterisation research programme in 1999. This initiative by the private sector led directly to changes in the structure and activities of the Department of Physics. It is important to observe here that UPE is a relatively new South African university, with what appears to be an emerging tendency to engage in science and technological research. The institution tends to be characterised by fragmented pockets of research activity, usually driven by individual academic champions. However, it has now shifted in its research policy and is well disposed to initiatives by academic units (Kruss 2005). This decentralised approach enabled the swift development of the network. The question is whether in the long term more support from the institutional centre may be necessary. In this case, the Department of Physics benefited from the attention of private sector partners who knew exactly what they wanted. Such a scenario may not necessarily be the rule and other departments at UPE seeking network opportunities may need to develop the skills of outreach and of creating conditions in which network links can easily evolve.

The research project was established in 2000 by agreement between Aberdare, Corning and the UPE Department of Physics. Telkom joined the group in 2001 and THRIP funding was sourced in 2002. The budget was approximately R2.4 million in 2002, and this level of funding was expected to continue through to the end of the initial three year period in 2004. Funding was provided in roughly equal amounts by Aberdare, Corning and Telkom SA, as well as an equivalent amount from the THRIP programme. Figure 3.1 provides an overview of the structure of the network.

The PMD research project is formally located in a 'Telkom Centre of Excellence' (CoE), which underlines the importance and potential influence of that corporation in the network. The Telkom CoE programme is a national initiative aimed at developing research capacity and output in science, engineering and technology through promoting postgraduate research in communications technology and related social sciences. It seems to be both a form of corporate social responsibility programme and a potentially strategic intervention aimed at improving human resources development in R&D in the field of telecommunications. Now that Telkom has bought into the PMD programme, it appears to be committed to giving support on a long-term basis and has asked the Physics Department to prepare a five-year plan for the optical fibre unit.

Dynamics of interaction within the network

As a Telkom CoE, the PMD programme must operate formally according to a charter signed by each partner. The CoE has a steering committee on which each partner is represented and, in terms of this structure, all partners are equal and must plan together and agree on strategic issues. The CoE has influenced the legal and structural shape of the network, but has only to a lesser extent shaped actual interaction between the partners.

The network partners reported that a good relationship exists between them, and to date no significant tensions or conflicts have arisen. Nevertheless, there are clear differences in how the partners relate to each other. The PMD project is headed by a professor from UPE, and the Physics Department takes the intellectual lead in the research design. The department has played a central role in building and servicing relationships in the network and has managed to establish a supportive and trusting relationship with each partner individually. However, it is the partner with the least power because of its dependence on the other partners for funding.

Moreover, while the research programme is owned largely by the three private sector partners, the actual nature of interaction puts the main emphasis on the relationship between Aberdare-Corning and UPE. This balance of involvement and power lies in the nature of the research on Aberdare's cables, which has required that students and staff have regular access to Aberdare's factory to carry out measurements, and interact with the production manager and technical staff members. The close proximity between these two organisations, both based in Port Elizabeth, facilitates frequent visits and regular contact between UPE and Aberdare – and, through Aberdare, with Corning. This has helped to build a strong and fairly informal networking relationship. The research team also shares codified knowledge gained from reading current journal articles relevant to the research, and the insight of the Aberdare technical staff into the phenomenon of PMD has grown through their engagement with the UPE research team. Such a bilateral link becomes even stronger, given that the person who represents Corning also represents Aberdare on the formal project management committee.

Pre-existing relationships between individuals often facilitate the formation of partnerships between organisations and can contribute to their success. The senior manager and key link person at Aberdare was a former master's graduate from UPE and knew from personal experience that the Physics Department had the research expertise and potential capacity to carry out PMD research. This reservoir of expertise, the pre-existing academic link with the Aberdare manager, and the physical proximity of the organisations, made the department a natural research partner for Aberdare, and has contributed significantly to the ease with which these two partners now relate to each other.

In the case of Telkom, the corporation established an overall CoE management team to represent and oversee its interests in all 14 CoEs that it funds nationally. This team is therefore not dedicated to the PMD project only, and significantly, is based in Gauteng, making communication between Telkom and UPE less regular and more formal. Team members attend all CoE steering committee meetings and handle CoE management matters and issues related to the research projects being carried out at the UPE CoE, including the PMD programme. When direct collaboration is required with Telkom on some technical aspect of the research work, or even on arranging logistical matters such as gaining access to a Telkom line to conduct PMD measurements, the CoE management team is not well placed to assist. Access for conducting field measurements is extremely difficult, even for Telkom's own employees, because of the security established to protect the line, and the Telkom CoE management team has struggled to arrange access for the UPE research team. Furthermore, it has been difficult to establish a relationship with any specific individual within Telkom structures who can support the programme and facilitate the research projects on the technical side. In recognition of these difficulties, a technical person has been assigned by Telkom to collaborate with UPE on the technical aspects of the research.

Telkom wields significant economic and political power in the telecommunications sector, making it an extremely powerful partner. For this reason, there was a sense from project partners that in many ways the success of the programme has depended on Telkom's support. Yet the Telkom relationship appears paradoxical. Despite the advantages that appear to come out of the programme for Telkom, it has thus far operated at a distance. This may be because the corporation views the CoE programme more as an investment in social responsibility than as one from which strategic research outputs may emanate – suggesting that Telkom has not fully appreciated the value of the PMD programme. Alternatively, the problem may be on account of the size of the corporation within which its own CoE management committee needs to be restructured. Interest in PMD may increase when Telkom goes into direct competition with the second network operator and seeks to sustain competitive advantage. Additional impetus for Telkom to engage with the

PMD programme may also derive from the tendency towards an, 'increasing number of strategic technology partnerships', to enhance competitiveness (Santangelo 2000: 1015). Indications are that, under the influence of these factors, greater interaction between Telkom and the CoE PMD programme will take place.

Serving the needs and interests of partners

In a competitive market, information has a key influence on value chains and has the potential to create competitive advantage in existing industrial configurations, or to bring about radical change in sectors. Hence the three enterprises collectively seek to invest in a research activity that has the potential to add value at several points in the chain of economic activity leading to the provision of data-transmission services. The interest is in measuring and monitoring PMD throughout the process, from manufacturing to the handling and installation of optical fibre cable in South Africa:

- For Corning, the measurement of PMD ensures that its standards are upheld internationally;
- For Aberdare, measurement of PMD during and after bundling of the fibre in cables is a means of quality assurance of their manufacturing process;
- For Aberdare, measurement of PMD during the manufacture of fibre optic assemblies, connectors, splice box enclosures and accessories is used to ensure that PMD tolerances or limits are not exceeded;
- For Aberdare, measurement of PMD may be applicable to new additions to its product range – such as aerial cabling and optical ground wire – for African applications;
- For Aberdare, measurement of PMD after installation by its own telecomms section – which provides a full cabling service – can assure quality;
- For Telkom, as Aberdare's client, a set of recommendations detailing best practice cable-deployment procedure would enable it to identify and eliminate the key factors that introduce unwanted PMD;
- For Telkom, the client, measurement of PMD after installation makes it possible to quality-assure their network independently, whether this is supplied by Aberdare or by any other provider; and
- All the participants can benefit from access to information regarding the effect of South African environmental conditions on fibre optic products, which will lead to improvements in deployment techniques.

In this case, the research activity informs several steps in the value chain, largely because its purpose is to quality-assure the performance of a particular material under different circumstances. This can be construed as research activity that produces a new artefact – a concept of measurement that can be applied – that does not inherently seek to change the process or phenomenon being investigated. By contrast, most research activity undertaken in collaboration with the industrial sector is oriented towards actively changing a product or process in some way, or creating new products or new processes. The participants observed that this research was focused largely on applying pre-existing knowledge to the phenomenon of PMD, to solve a problem in the context of an application. Nevertheless, measurement of the phenomenon may at a future point trigger further research, based on the need to improve specifications.

For the UPE Department of Physics, the programme offers major opportunities by generating substantial funding for acquiring new equipment and for bursaries. It also provides a new area of research and a strong link to industry that has enabled it to attract post-graduate students. In terms of direct transfer with industry, the department has registered at least two managers from the industry partners for master's level degrees.

Both codified knowledge applicable to PMD and its measurement, and tacit knowledge – applied knowledge about the cabling process and conditions under which the fibre must perform – are communicated through the network. Knowledge production and transfer within the Physics Department is primarily science-driven and hence, codified knowledge is extremely important. Much of the knowledge on the use of laboratory equipment and measurement processes is, however, tacit and its transfer relies on students working together in the laboratories. The results of the research have also been shared through papers presented at Telkom's annual South African Telecommunications Networks and Applications Conference (SATNAC) and the South African Institute of Physics (SAIP) conference. The department has also moderated and certificated a training course run by Aberdare for one of its customers.

The PMD research will be particularly useful to Telkom, because much of its legacy network is expected to be PMD limited, and an accurate audit is essential for upgrading and for the introduction of new technologies and services. An audit would reveal the maximum possible data-transmission rates supported by various parts of the network, and would make strategic decisions on replacement or alternative routing possible. For Aberdare-Corning, the acceptance by Telkom that understanding of PMD is a legitimate optical fibre parameter that needs to be considered and is not just a marketing device, is an important outcome of the programme.

The future of the network

To date, the research has shown that the cabling process at Aberdare is of high quality in that it does not adversely affect the PMD of the optical fibre. In some senses this is a negative outcome in that PMD measurement has had little direct impact on Aberdare's manufacturing process. The research has, however, given Aberdare an advantage that it can use against its competitors. Aberdare can now specify the PMD value of its cables, and market these as having high data-transmission rates. Aberdare thus also uses the programme as a marketing tool and occasionally brings customers to the university to view the laboratory.

Aberdare sees three possible futures for the programme. First, it could pursue research to identify an appropriate procedure for measuring PMD in the factory for quality control purposes. This would incorporate developing a suitable commercial instrument for plant implementation. Second, Aberdare feels that the long-term sustainability of the research programme could be secured through the establishment of a training and consultancy service for both the public and private network-provider markets and through projects designed for commercialisation. Third, the research team was planning to investigate the design and development of a PMD compensation system that could be used by Telkom to extend the life of fibre lines that have been deployed for many years and have bad PMD values. This research was planned to begin in 2004, as cutting-edge work that should lead to the building of a prototype. The research into PMD compensation should lead to innovation and offer strong opportunities for commercialisation.

Challenges

Many of the challenges for network interaction echo those noted in the biotechnology cases, and some are likely to resonate across all four case studies.

First, higher education institutions and industry come into networks from different perspectives and work on different time scales, which can cause tension. For example, the interaction with their higher education partner has not turned out entirely to the satisfaction of Aberdare who are disappointed that the programme has not yet produced any graduates who have gone into the company, assisting in meeting its human resource needs. There appears to be a tension between Aberdare's relatively high-level research needs on the one hand, and its need for less theoretically saturated employees for daily operations. Aberdare is concerned that the programme may be producing graduates that are at a level of research and theoretical sophistication that is too high for South African industry, given the low volume and low complexity of the research and development being carried out. Aberdare would like the programme to produce bachelor or honours level graduates who are knowledgeable in the physics of optical fibre technology, and who can be employed either in the factory or in the commercial side of the business. In particular, Aberdare is hoping the programme will generate black and female graduates so that it can improve its equity profile – a goal shared by Telkom.

Second, the higher education research partner needs research capacity, skills and maturity to be able to carry out research in partnership with industry. Higher education institutions with a longer track record of involvement in R&D with industry need to have a greater critical mass of the tacit knowledge required to manage research, which can be brought to bear on new project work or in new areas.

Case study 2: Free-space optics project

This case study focuses on a research network generated between a set of organisations aiming to develop a viable means of broadband data communication based on free space optics (FSO) (also termed free space photonics) – the transmission of modulated visible or infra-red beams through the atmosphere. This is achieved by linking a high powered optical source (such as a laser) with a receiver, by means of lens systems at the sending and receiving ends.

Free-space optics systems are a potential alternative to other telecommunications media such as fibre optics and radio frequency technologies, for a number of reasons. The installation of fibre optic cables can be a lengthy and costly process, especially in urban environments where pre-existing infrastructure can impede cabling entirely, and where urban planning for cable laying must be undertaken years in advance. Because FSO is transmitted through space it represents a more flexible solution that can be quickly implemented. The use of radio frequency technologies is extremely costly and requires spectrum licences from regulatory authorities which have to deal with multiple demands on radio frequency space. Given the competition, these licences are difficult to obtain. FSO systems, however, use a light spectrum that falls outside of the regulatory control that the Independent Communication Authority of South Africa (ICASA) has over radio and microwave frequency bands.

As a broadband telecommunications instrument based on wireless transmission, FSO is suited to cross-border communications, as well as for mining infrastructure and other environments where cabling options present difficulties. FSO can also be deployed as a temporary solution, such as while fibre optic cable infrastructure is under installation, or where infrastructure has been damaged and requires an emergency stopgap. Furthermore, there is increasing interest in using FSO as a mainstream telecommunications technology. Internationally, the slump in investor confidence in the world telecommunications market has caused enterprises to investigate alternative cost-effective ways of data transmission.

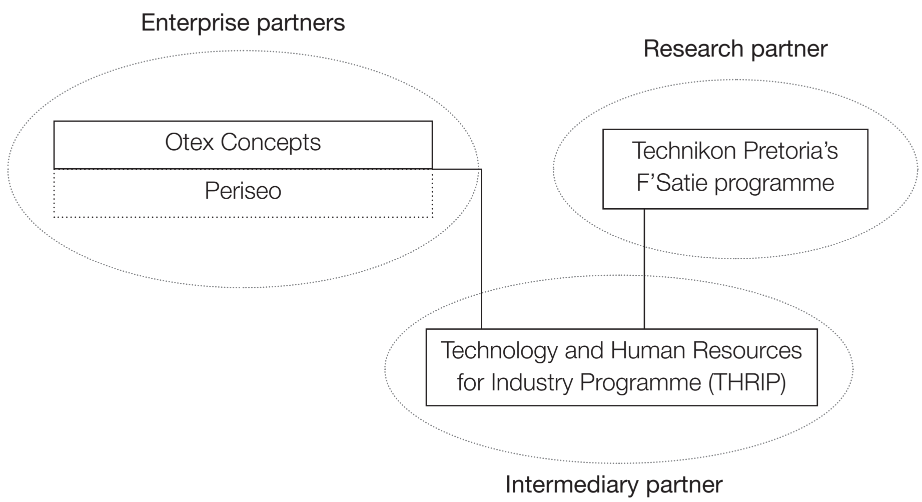
Free-space optics technology has been in existence for nearly thirty years, having been applied by NASA in the past, but technological and economic circumstances around the recent turn of the millennium have revived interest in its potential. Thus research activity that explores FSO is likely to be characterised by a problem-oriented orientation rather than by a disinterested scientific approach. In particular, researchers will want to resolve some of the challenges associated with FSO signal transmission, including absorption of the signal by physical matter in the air, scattering caused by signal interference, distortion caused by heated air, and so on.

Product and research roles

Figure 3.2 maps the relations between the three organisational entities integrally involved in this network, which initially appears simple:

- At the enterprise node, the SME Otex Concepts, and the SME Periseo;
- At the higher education node, the French South African Technical Institute in Electronics (F'Satie), a higher education entity based at the then Technikon Pretoria, which provides a means for networking between enterprises and individuals in the ICT R&D field; and
- At the intermediary node, the NRF which provides THRIP and TIPTOP[2] funding.

Figure 3.2 The free-space optics research network



This section will describe each entity, and their interest in the FSO network.

Otex Concepts was established in Pretoria in 1994. In 2003, it employed ten people – of whom eight were technical staff – and had an annual turnover of R6.2 million. Otex specialises in problem-solving product development in a range of telecommunications environments: telecommunications, network communications, FSO laser communications, and fibre optical communications. The company specialises in the NetShield range of FSO products, which means that it can establish a preferential relationship with the NetShield supplier.

2 Technology Innovation Promotion through the Transfer of People – a THRIP scheme funding exchanges between industrial company staff and university students.

Otex is a 'research and development house' in a non-traditional sense, being based on a business model that involves assembly but not manufacturing. Hence it avoids the risk of undertaking component development costs in a technologically fast-moving field. It is thus to some extent restricted to the application of technologies currently available in the market place. The company relies on keeping up to date with international trends, and with such new technologies and innovations as may be represented as new components on the market. Such new products may open up possibilities for creating unique combinations of components. Based as it is on the added value of bringing technologies together, Otex research is synthetic and problem-solving rather than fundamental. To Otex Concepts, R&D and new knowledge are obviously paramount to competitiveness, and up to 20 per cent of net profits are invested in research and development.

The Otex business model is also based on identifying the needs of industry early and developing workable concepts and practical solutions for industrial communications problems in specific enterprise contexts. The telecommunications electronic engineering field in South Africa is fast developing and relies on rapid responses to specific on-site problems. A number of the larger networking and telecommunications enterprises lack in-house expertise for very specialised product development; smaller organisations focusing specifically on resolving particular kinds of problems have thus found a niche in the market.

The focus for Otex is on exploiting and adapting existing technologies to solve specialised industry problems at the enterprise level. Its relatively large technical staff is required to liaise with other enterprises that are sub-contracted to supply them with components and to repair Otex's own products. Otex places emphasis on quality of product assembly (with a lifetime warranty) and guarantees a 48-hour response time on equipment breakdowns. From this it is clear that the company is aware of the importance of the value-added dimension of service to its clients, especially in the telecommunications field where loss of connectivity and data-transfer time must be minimised.

The project initiated by the partners in this network is an attempt to create affordable, locally developed FSO systems for local telecommunications and networking companies. The process of importing FSO technology into South Africa is said by the enterprise partners to be slow and expensive. Many small enterprises cannot afford to undertake such a project where there are substantial up-front investments, on account of protracted delay of income generation, the risk of unknown returns, or the possibility of failure. According to Otex, which holds the intellectual property rights, the NetShield FSO branded product is the first of its kind in South Africa. For Otex, holding the intellectual property rights represents a considerable advantage in that this gives it the security to pursue further development. This is important in a small market such as South Africa, where there are already two other local enterprises offering similar FSO-technology based systems.

The FSO system has already been sold by Otex to organisations in the USA, Japan, Mozambique, Botswana and Angola. Having successfully entered two highly technologically advanced economies (the USA and Japan) is an enviable achievement, but the product is also being sold in southern Africa. This suggests that Otex and its collaborators are pursuing a strategy of product differentiation within the world market.

Otex's key enterprise partner is Periseo, a specialist electronic design and development company established in 2001 and based at the Rand campus of Pretoria Technikon. In 2003 it had a complement of three employees, including the manager/owner. Periseo has worked in several industries such as telecommunications, military, aviation and security.

It has worked with a wide range of products that includes opto-electronic products, such as particle detectors, infra-red perimeter beams and FSO communications. Periseo relies on the development of new and innovative products addressing specific client problems and therefore places significant emphasis on research and development for sustainability. The owner stated that he spends approximately 20 per cent of his time on R&D, which involves the application of new technologies to form innovative products.

The telecommunications sub-sector in South Africa is dominated by a few large and medium players with a multitude of smaller enterprises which either support the larger enterprises or engage in independent entrepreneurial activity. Periseo and Otex fall into the latter categories of enterprise, which, on account of their small size and large numbers, will not be in a position to allocate a significant amount of their resources to seeking network opportunities with potential collaborators or information-gathering about potential competitors. They are likely to have a local view of the industry, bounded by their own informal and formal networks of contacts. Such firms would benefit greatly from an external agent that provided both information about other enterprises and an institutional mechanism for interaction. This is precisely the role of the third participant in this network.

The French South African Technical Institute in Electronics (F'Satie) is based at Technikon Pretoria. Established in 1996 as a high-level electronic technology institute by a consortium of French government and South African government ministries, the unit received a R10 million grant, split between French and South African donors, as well as a French seconded director who is a professorial-level electronics specialist.

F'satie had a strong educational programme leading up to doctoral level, which emphasised student exposure through laboratory and project work undertaken in industry partnerships. However, the Institute struggled to meet competing demands from stakeholders, and a major failing was its lack of success in bringing academics from the Technikon firmly into the programme. Technikon Pretoria is considered to be the top-performing technikon in South Africa as regards research activity, but must nevertheless be considered an institution with emergent rather than developed R&D capacity. Academic staff have heavy teaching loads and seem not to have been attracted to the financial potential of taking on projects in F'Satie, claiming to have little time to spare on such activities.

The Institute took a decision to be more proactive in industry through the establishment of an incubator programme, the Incubation Centre for Technological Innovation (Incentif). This was floated partly in response to major restructuring among large enterprises in the electronics and electronic engineering sectors, many of which had serviced the military needs of the apartheid state. The restructuring brought job losses that made available a pool of highly qualified engineering personnel.

Through the Incentif programme, F'Satie is the central point of contact for a large number of people with industry-based expertise who can share the Institute's facilities, and increase their capacity to take on projects by employing BTech and MTech students as assistants in laboratory work. According to the Deputy Director of F'Satie, this is an ideal scenario, where students are able to access industry-level expertise within the academic context. This free-floating pool of expertise permits the flexible development of project teams, constituted in accordance with the requirements of many concurrent projects with different outputs, and different needs in relation to expertise. In this way industry experts, rather than academics from the higher education sector, work as 'product developers' in F'Satie enterprise partnerships.

The Incentif programme was furthermore intended to provide a structure within which industry expertise and student capability could be drawn into the growing SME sector. In 2003 there were about thirty SMEs working with F'Satie through the Incentif programme, in which nascent SMEs are offered access to office space, laboratory equipment and administrative services. In exchange, they are required to provide teaching services, to manage student practicals in F'Satie laboratories, and to be available to be contracted onto F'Satie projects. In addition, many of the projects involving SME partners are THRIP-funded through the TIPTOP programme, which provides funding for salaries to cover project work. The FSO thus qualifies for support from THRIP. SMEs frequently work on multiple projects that may involve trans-disciplinary problems, and require access to a wide range of expertise that would ordinarily be unavailable to them. The Incentif programme facilitates the availability of this expertise across sub-fields of electronic engineering, and contributes to developing greater SME internal capacity and independence in the medium to long term.

Construction of the network

In practice, the roles adopted by each network player are complex, and belie their apparent location at a particular node. F'Satie may be characterised as a partner at the higher education node, given that it is located in a technikon, but it is not acting directly as a research partner in the network. In practice, its focus is to facilitate research networking, bringing together enterprises with students and infrastructure, based in a technikon. For this reason, its role may be understood more properly as that of an intermediary organisation.

This is illustrated by examining the original establishment of the network. The managing director of Otex Concepts decided to pursue avenues for developing FSO technology in South Africa, given that the company had the necessary electronic expertise but required additional optics specialisation for product development. This led Otex to approach Technikon Pretoria for assistance and through this contact, become aware of F'Satie's Incentif programme. Periseo was then sub-contracted by F'Satie as the research entity for developing the required optics product. On this basis, F'Satie applied successfully to THRIP for project funding over a three-year cycle.

F'Satie fulfils several roles: as a broker of skills and opportunities between SMEs, industry experts and students, as a conduit for obtaining state funding through the THRIP programme, and as a bulletin board for communication within the community of individuals and enterprises. Its primary responsibilities in the network are to administer the THRIP funding and to manage the overall relationship between Otex as the main client, and the research entity, Periseo. Lastly, F'Satie is responsible for managing the allocation of students to the project and ensuring that Periseo supervises students in the agreed manner.

Periseo's primary responsibilities, despite its formal status as a 'secondary enterprise', are to manage the project research from a technical perspective (optics development) and to supervise the laboratory work done by participating students. The company has also invested time in sourcing and purchasing optics equipment and setting up the laboratory to suit the specifications of the project.

Even though Technikon Pretoria acts as the project leader, it is clear that F'Satie does not act as the primary research entity. In this sense the case is atypical, because the actual research activity is transacted between two enterprises and has no involvement of senior research academics at the technikon, using only post-graduate students. The case study is thus an example of how enterprises can contract other enterprises to conduct research, without substantial or direct higher education participation. Had the technikon been able to provide competing research services, it would have been interesting to observe whether Otex would have contracted its research needs to the technikon or to SMEs. This implies that if a significant component of South African R&D is commercialised, then higher education institutions will have to actively develop their capacity to compete. The fact that Technikon Pretoria hosts F'Satie is testament to the depth of its aspiration to do so, but the reported resistance on the part of academics to becoming actively involved is a major constraint on the realisation of a new institutional vision (see Kruss 2005 for elaboration).

The value of F'Satie as a broker and facilitator did, however, lead specifically to the link between Otex and Periseo, without which this network might not have existed. This suggests that more attention must be paid to how such intermediate actors catalyse networking and what the best practice for this type of activity might be.

Network structure and dynamics

The network has a nominally flat structure, but there are different levels of management. At top management level, F'Satie, Otex and Periseo meet once a month to discuss matters pertaining to funding, space and equipment. In the initial phases of the project, interaction was relatively formal and Otex's primacy in project decisions was clear. As time passed, however, interactions became less formal and more focused on problem-solving strategies at the research-team level.

At the next level, the design team has technical meetings approximately once a week to discuss progress and problems related to product development. Key research interaction takes place entirely between the private sector partners. Proximity is a positive influence, since the participants are all based in Pretoria. The team – including technikon students and partners – works closely together to develop technical solutions to problems in a laboratory setting. Tacit knowledge is viewed as critical in the design and development process, and problem-solving is at the heart of research and development activities.

According to Otex, a trusting relationship with employees is critical, so that blueprints for innovations will be protected from competitors. Theft of concepts is a prevalent reality in the SME sector that has to be guarded against, since smaller organisations do not have the time or money to pursue lengthy intellectual property rights litigation.

F'Satie considers knowledge transfer to students as paramount – the worlds of education and work are brought closer together because students are working on real projects and products within specified time frames, whilst being supervised by industry experts. However, they do recognise that not all students have sufficient knowledge of theory to allow them to participate effectively in projects.

Delays and the bureaucratic requirements of technikon and THRIP funding mechanisms were seen as being inimical to the quick decision-making needed for product development. The technikon's administration department is reportedly working hard on streamlining funding, and THRIP requirements, though complex, are improving.

Serving the needs and interests of the partners

The relationship between Periseo and Otex Concepts was set to continue beyond the THRIP funding cycle that ended in 2003. Otex signed a separate contract with Periseo to continue their activities as consultants on the project. Periseo is also doing other work for Otex involving the development of specialised software. The two organisations have even mooted the possibility of a more long-term commitment on the FSO project. A strong sense emerges that once trust has developed, each partner becomes more broadly concerned about the sustainability of the other, quite beyond the scope of the project. A further benefit of this relationship is that Otex is able to bring in external expertise on a contract basis to supply immediate development requirements in a flexible manner.

Periseo is a relatively new and emerging enterprise and its relationship with Otex has resulted in decreased reliance on F'Satie and an increase in its own growth and independence. Crucially, the SME has benefited from the financial input of THRIP and from increased experience in the optics field, simultaneously allowing it to expand its business profile.

F'Satie has benefited from the setting up of a complete opto-electronics laboratory, with all the necessary equipment, at Pretoria Technikon. The laboratory is being managed by Periseo while the FSO project runs its course, but all the equipment belongs to F'Satie. The Institute has thus been able to develop a knowledge base in the optics field. A less tangible benefit has been that work on specialised projects with industry players and Incentif partners allows the development of 'market intelligence' and helps F'Satie to keep pace with the latest developments in the electronics field. There are indications that there may also be some profit for F'Satie from sales of the FSO product, a percentage of which – not yet agreed upon at the time of research – may increase if F'Satie is able to provide a marketing channel for the product through its own marketing and communication strategies. Nevertheless, the intellectual property belongs entirely to Otex. The success of the project itself is likely to have positive implications for F'Satie's status and reputation within the industry.

Case study 3: The Collaborative African Virtual Environment System project

CAVES, the Collaborative African Virtual Environment System, is a software development project aimed at developing an authoring tool for creating virtual environment (VE) applications. It is envisaged as a user-friendly tool that will enable 'non-programmers' to create interactive virtual environments for applications as diverse as education, games, therapy and shopping. The main challenge is to develop an authoring tool that is easy to use, but also versatile, so that interesting virtual environments can be created. Another feature of this technology will be to allow intelligent interaction between multiple users in one environment, as opposed to current computer game technology that relies mainly on the actions of one object on other objects in the environment.

The central goals are to develop a VE authoring tool (software), a methodology (set of specifications) and a platform (hardware) that meet three criteria:

- The authoring tool must be user-friendly for users who are not programmers, yet flexible enough to allow for multiple applications and creative uses;
- Virtual environments that are generated must be emotionally engaging and capable of creating a 'sense of presence' for end-users; and
- The technology must be affordable in an African context.

Virtual environment is a relatively new technology within the multimedia sector. It was of particular interest to the military but is rapidly being explored for a host of other applications such as multi-user domains (MUDs), virtual prototyping, tele-operator systems in medical environments, and real-time surgical simulations. Research interest is focused on psychophysics, haptic interfaces to simulate touch experience, temperature perception and perception of self-movement in virtual environments, and so on. One of the CAVES' partners, Harvard University, is developing 'Museum-Related Multimedia and Virtual Environments for Teaching and Learning Science' and similar work is being done in the field of archaeology (http://muve.gse.harvard.edu/muvees2003/index.html). These are complex technologies that will require innovation to be rendered more generally accessible.

It was decided to create three test scenarios with very different contents and targeted end-users, through which to develop and demonstrate the capacity of the CAVES authoring tool. Each scenario is designed to test a particular aspect of VE technology, and to contribute to the project's overall objectives. These are:

- An educational games scenario, developed to test aspects of collaborative systems where multiple users can interact with each other, as well as with virtual objects in the environment;
- An African culture scenario with San storytelling as its specific content, designed to explore audio techniques that will enhance the sense of 'presence' experienced by end-users of the VE technology; and
- An application in HIV/AIDS therapy, which focuses on the combined use of informational and emotional IT support to promote awareness and provide information in a psychologically sensitive virtual environment.

The bandwidths available for IT transmission in South Africa are limited. To overcome this restriction, research is also planned to investigate geometric connectivity compression as a mechanism for reducing the significant storage requirements of VE software.

The three test contexts of application, as critical intermediate products of the project, will drive development. The products from this process are intended to serve as demonstration models, given that a technology such as VE can really be appreciated only through concrete applications. The scenarios are a key deliverable in terms of its Innovation Fund conditions, which require that the project must yield a product that can be commercialised. The scenarios may be the key for convincing prospective investors to support further applied research or ventures to exploit the CAVES methodology commercially.

Virtual environments are not easy to design and the programming involved is very complex. The programming language has to be 'hidden' from the end-user, and there is normally a trade-off between ease of use and flexibility, that is, in the range of design options that are available to the user. An important challenge for CAVES is to reduce the need for such a trade-off by developing a VE technology that optimises both user-friendliness and versatility. Research and development work in CAVES has centred on audio- and visual technological innovations to achieve the desired degree of presence for the end-user. This has entailed a strategic balancing act for the CAVES team.

By international standards, the multimedia industry in South Africa is small. The multimedia market is highly globalised, and South African companies have to compete internationally for key inputs. By far the greater part of the technologies used in the industry are imported from abroad. Probably because it is exposed to the full force of international competition, the South African multimedia industry is highly competitive. By South African, as well as international standards, costs of innovation are extremely high, making technological innovation beyond the financial scope of individual companies.

In addition, the capacity of the South African multimedia industry to play a strong participatory role in research and innovation projects initiated by universities and other research institutions is questionable. Two main reasons are given for the resulting doubts:

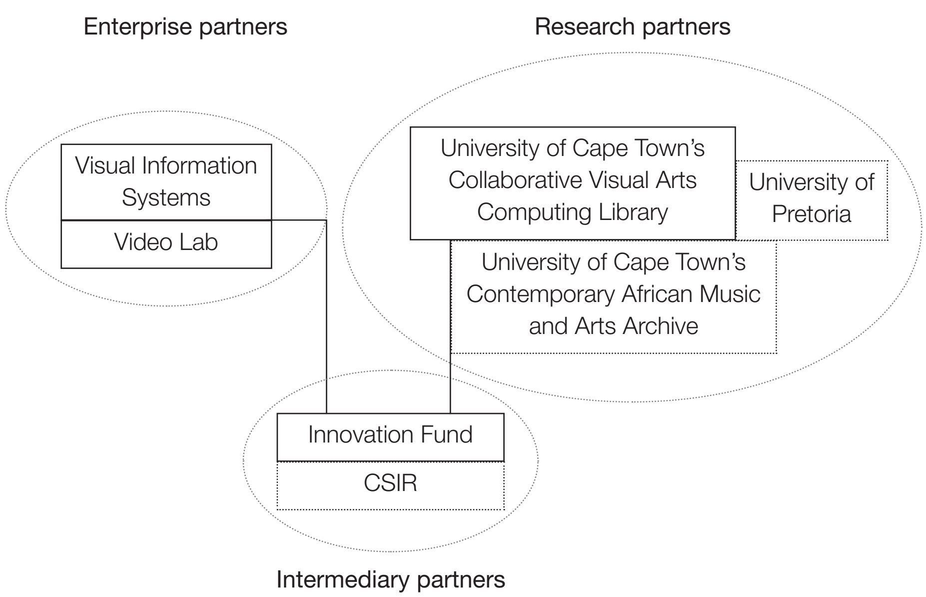
- Competition in the industry is fierce and depends almost entirely upon innovation, so it is unlikely that rival companies would join forces to invest in R&D work aimed at exploring new technologies; and
- Time horizons are notoriously short in the South African software sector. According to CAVES respondents, local companies typically work on one-year action plans, and some have three-year strategic plans, but five-year strategic plans are rare. By contrast, it is generally accepted that development of a new information technology product – from pure research to final application as a marketable product – requires a ten-year time frame.

Multiplicity of partners

The CAVES project was initiated in 2000 by the Collaborative Visual Computing Laboratory (CVCL) at the University of Cape Town (UCT), in partnership with five other organisations. The composition of the network has changed somewhat over time due to attrition in membership, and currently takes the shape reflected in Figure 3.3:

- At the higher education node, the CVCL and the Contemporary African Music & Arts Archive (CAMA) at UCT, the University of Pretoria (withdrawn) and the Council for Scientific and Industrial Research (inactive);
- At the enterprise node, medium-sized enterprises Video Lab, and Visual Information Systems; and
- At the intermediary node, the Innovation Fund.

Figure 3.3 The Collaborative African Virtual Environment System (CAVES) network



Collaborative Visual Computing Laboratory (CVCL)

The Collaborative Visual Computing Laboratory is a small, informal, self-organised research group, one of three such units located in the Computer Science Department at UCT. Its broad research focus is on human-computer interaction and computer graphics. Current research directions include virtual environments, computer graphics algorithms, medical imaging, collaborative systems, information technology policy and multimedia. This integrated approach to research and development reflects the view that IT is 'a universally enabling technology'. All major projects are ultimately directed at making IT more accessible and affordable for a wider spectrum of users.

Apart from state funding channelled through UCT, the unit generates much of its funds from project work. Two other major projects are:

- A South Africa Netherlands Research Programme on Alternatives in Development (SANPAD) funded project focused on the development of a voice-over-internet protocol to help cope with the digital divide in South Africa; and
- A project on broadband networks and tier applications as part of a Telkom Centre of Excellence project, involving the Innovation Fund, THRIP, Siemens and internal collaboration with the UCT Electrical Engineering Department.

Commercial applications have resulted from some of CVCL's research and development work, and senior staff members have (in co-operation with other scientists) applied to register patents. These examples suggest that innovative work is a characteristic of their approach.

The CVCL has four senior academic staff members and 22 postgraduate students, including twelve master's and three doctoral students, of whom 16 are involved in the CAVES project. It has links with several local and international universities, and collaborates with several South African industries. UCT is an academically strong university that has considerable experience of supporting academics who are involved in cutting-edge research, and has an established R&D capacity. In addition to the mature institutional base, the CAVES project benefits from the fact that the senior academic on the project was educated at Cambridge and, with experience of 'blue sky' research in the UK, has been able to bring together a critical mass of researchers and programmers. This means that there is a sizeable community of research practice concentrated in CVCL.

Visual Information Systems (VIS)

Visual Information Systems was established in 1996 by a former CVCL staff member who was one of the initiators of the CAVES project. The company became the first enterprise partner in the project. VIS is listed on the JSE Securities Exchange and, through successive transactions, is now located in the Lithotech group of companies, which is, in turn, a subsidiary of the Bidvest Group. VIS employs 18 people, including 14 professional or technical staff, most of whom are computer scientists and programmers.

The firm initially focused on the computer graphics field, but has broadened its services and is now able to cover general business applications. The move away from specialisation appears to have been driven by changes in the market. New R&D work is undertaken within VIS from time to time, when an internal need for innovation arises. There is no dedicated R&D staff component, because significant investment in product innovation is not considered a viable option in the South African market.

The company's interest in CAVES has waned over time as the business focus has changed. However, the personal interest and involvement of the VIS representative on the project grew to the point that in 2001 she was offered an appointment as its project manager. Apart from the direct compensation that VIS receives for the time that she spends on managing the project, there has been little further direct interest from VIS.

Video Lab
Video Lab was established in 1982. Since then, the business focus has metamorphosed. Over the years the company grew to become a leader in its sector, offering the entire spectrum of post-production facilities to users from the film, television and advertising industries. The company became part of the Sasani group of companies, which controls approximately 70 per cent of the multimedia market in South Africa. Video Lab's Cape Town branch opened in 1991.

The company's CAVES representative explains that part of its business ethos is to provide an environment that is conducive to creative work, since it serves the performing and commercial art sectors. Video Lab joined the CAVES consortium nearly a year into the project. The outcome of the CAVES research holds a potential attraction for Video Lab in the longer term, but it has no immediate commercial interest in the envisaged product. Developing useful applications of the CAVES VE technology will still take a few years and there is, so far, no guarantee that the project will yield a product that can lead to viable commercial applications.

Contemporary African Music and Arts Archive (CAMA)
Based in the Faculty of Science at UCT, and at the Montebello Design Centre, also associated with UCT, the Contemporary African Music and Arts Archive (CAMA) was established in 1995 with the aim of conserving and disseminating digital records of African cultural expressions and artefacts, and promoting cultural exchange among African countries. With funding from the Ford Foundation, CAMA has established Culture Africa Network (CAN) multimedia and digital video documentation studios, and field-recording units, in seven African countries since 1998.

The Contemporary African Music and Arts Archive has been involved in the CAVES network almost from the outset. The unit has an immediate interest in the VE technology being developed, as it could offer a vivid, emotionally engaging medium for capturing and presenting African cultural material and artefacts. A specific application envisaged for the technology is the creation of a virtual museum to make available elements of African culture that are not readily accessible. San storytelling was chosen as the content – and context – for this exercise. The aim is to investigate the manipulation of sound sources to create a spatialised sound effect using surround-sound recordings and dynamic pre-mixing techniques. This entails recording each sound separately and attaching a responsive/reactive programmed sound file to each individual element in the environment.

Council for Scientific and Industrial Research (CSIR)
Initially, the Council for Scientific and Industrial Research (CSIR) was actively involved and, in line with the intermediary role it typically plays, was expected to manage the CAVES project. However, its involvement in the network has tapered down over time, and the senior staff member who represented the CSIR in the CAVES consortium resigned in 2002. As a result, the organisation now hardly plays any role in the project. This gradual withdrawal is ascribed to some or all of the following reasons. First, the geographical distance between Cape Town and Pretoria appears to have made direct CSIR participation difficult to sustain. Second, one of the business representatives on the consortium speculates that the research functions of UCT and the CSIR in the project were not distinct, which resulted in a measure of professional competition between researchers from the two institutions and unease within the consortium team. The situation sketched here shows how, in spite of a formal understanding of roles as expressed in the Innovation Fund contract, there is a danger that research entities can jostle for primacy

in a network, either in pursuit of the academic credit that is perceived to be inherent in the project, or in pursuit of the financial and equipment rewards that may accrue to the primary role player. The CSIR retains a formal place in the consortium, but is no longer actively represented at consortium meetings.

University of Pretoria
The University of Pretoria (UP) was initially a partner in the CAVES consortium. However, after a year the university withdrew, by mutual agreement with CVCL and the other partners. Two reasons were given: firstly the key Pretoria-based researcher with an interest and experience in VE had left the university to return to the UK. Second, once it had become evident that the project would not meet the university's expectations in respect of acquiring sophisticated new equipment, the institution appeared to lose interest. After UP's withdrawal, research within CAVES was based entirely at UCT.

The dynamics of an Innovation Fund incentivised project

CAVES is a three-year project that was initiated in the second half of 2001, with substantial funding from the Innovation Fund. The project proposal was formulated by the present project leader and a senior colleague at CVCL, and inspired by a forerunner project at the CSIR. There were two reasons why the project was established as a partnership between a higher education institution and partners in industry: firstly, to qualify for funding from the Innovation Fund, and, secondly, because an industry partner was needed to focus the technological innovation on a concrete application for a particular user-market environment.

The Innovation Fund is the sole funder of CAVES. Subsequent funding applications to the JM Lloyd and Rockefeller Foundations for development of the application scenarios were unsuccessful, possibly because CAVES had already received generous funding, or because the project was not considered a good funding prospect. The scale of funding required is far beyond the reach of South African private sector investors. Without Innovation Fund investment, development of new technologies such as VE would not be possible. If it is successful, the Innovation Fund investment should bring substantial activity into the emergent multimedia industry in South Africa. Furthermore, in addition to purely financial motivation, the funding enables CVCL staff and students to do innovation work that could make a meaningful contribution to social development in South Africa.

The roles of several of the partner organisations in the CAVES network have changed over time, resulting in unanticipated effects on the work of the project and on dynamics within the network. According to one respondent from industry, this emerged clearly from experience in the first year or so of the project, where three research partners (the CSIR, CVCL and UP) jostled for primacy. The subsequent withdrawal of UP, and reduced involvement of the CSIR, showed that ambiguity or overlap between the roles of partners could result in competition and 'turf battles', which would clearly be counterproductive in a collaborative endeavour.

When the first year (one third of the project's full term) had passed, there was little evidence of progress and the available funding had remained largely unspent. This prompted the Innovation Fund to commission an interim review of CAVES by an external consultant, which led to significant structural changes in the network. According to respondents, the review also served as a vital catalyst for galvanising the consortium team, whose members had previously worked together on a much looser basis. Measures that were taken strengthened the management of the project and led to considerable improvements in productivity.

This experience highlights the importance of project management expertise in R&D projects of any size, duration or budget. In particular, the South African ICT industry has, since the late 1990s, suffered a shortage of project-management skills, to the extent that recruitment agencies have been known to seek out project managers in other disciplines for immersion in the ICT field. Although project management is a generic competence, in this case it needs to be embedded in the context of ICT processes and knowledge.

In 2003 research and development work progressed steadily. A significant point has now been reached in the development of core hardware and software technologies, where the first generation of application models is approaching completion.

The Collaborative Visual Computing Laboratory continues to provide intellectual leadership. The team leader oversees the work of the researchers – all CVCL staff and post-graduate students – who generate the new knowledge that in turn informs development of the new VE technology. The administration and financial management functions of the project are also located in CVCL. In 2002 a project manager was appointed, based with VIS. At the time of the research she was managing applications development in CAVES and overseeing the work of the programming team, in consultation with the team leader. Operations (programming and applications development) and further technology development are undertaken by three interrelated teams: a team of four programmers; a methodology group, responsible for developing the three application scenarios; and a group of researchers. All team members other than the four CVCL staff members – who are all UCT employees – are contracted directly to the project.

Video Lab's contribution to the project was to place the company's technical equipment at the disposal of the innovation team, but this option has hardly been exercised. Instead, the major contribution from Video Lab came in the form of expertise in multimedia. Their representative on the project is a leading businessperson, highly experienced in the multimedia industry, who has contributed valuable guidance to the team about applying business principles and practices to managing the project, and targeting the products at potential business users and investors. He has played an important role in introducing CVCL staff and the other consortium partners to the network of media enterprises in Cape Town.

The Contemporary African Music and Arts Archive plays two main roles in CAVES. Firstly, it directs work on the African culture scenario that will take the form of a San storytelling environment. Secondly, arising from this, CAMA has taken a leading role in overseeing research and guiding development of the audio-component of the VE technology. Because CAMA has a direct and immediate need to apply the VE technology in its work, it has consistently urged the team to prioritise the innovation work of the project. In this sense, CAMA has simulated the role of an enterprise partner concerned with the product's application, and is potentially a key future enterprise partner with a commercial interest in the product. However, possibly because CAMA does not have the status, resource base and market awareness of a commercial business partner, it has had limited power to press for a particular focus or accelerated development process.

The case study reveals how especially – but not exclusively – in the software industry, there is a convergence between research agency and client in the R&D process, which can ensure that the product will more closely meet the client's needs. A feedback process in which the client is integrally involved is also a characteristic of this fourth case, suggesting that where projects are driven by basic rather than narrowly applied research, closer interaction between client – or client surrogates – is a necessary part of the research process itself.

Given this picture of a project in which partners are reducing their levels of commitment for different reasons, we need to question the ambitious nature of the CAVES software project. We can refer to 'minor software products' that involve incremental innovation, carry out minor tasks or complement larger established software products (for example, ZipAdvisor, which analyses free space on hard drives). On the other hand, 'major software products' typically involve radical innovation and are comprehensive enough in scope to enable many tasks. In addition, such major products are often stand-alone (for example, word-processing software). Clearly, the magnitude of the CAVES project is closer in scale to major types of software products.

There are different ways in which firms can outsource parts of the process. This is an option, partly because of the modular nature of software, and partly because of the open technological standards that characterise high technology fields. There is a variety of different approaches to new product development in the software field, but almost all will include the generic steps from concept generation and evaluation through project planning, design, coding and testing, to commercialisation (Nambisan 2002: 141–165).

In the case of the CAVES project, it is clear that not only is this a significant software development undertaking with a substantial innovation demand, but virtually all of the project activities are absorbed by the CVCL – rather than by the Innovation Fund consortium as initially planned. This concentration of effort raises the question as to whether such an undertaking is achievable given limited resources and time, in the light of loss of partners and a shortened time frame.

Knowledge dynamics in innovation research

Although the knowledge generated within CAVES is highly technical, it is generally codified knowledge. In the rapidly developing IT field, new knowledge is being generated all the time. Terminology is continuously being codified within the international community of specialists. These are research areas in which international communities of practice and their associated technical languages are just emerging. The aim of CAVES to make VE more interesting has taken the project to the forefront of international development of this technology.

Research and development work to extend the scope of VE to capture a sense of presence places the project at the interface between computer programming and psychology. Tacit knowledge is used in the programmers' efforts to establish connectivity between the two disciplines. The project leader explained that the highly talented lead programmer (a CVCL PhD student with previous experience in commercial programming) had to follow his intuition when it came to 'navigating the vague specifications' provided by the artists, educators and psychologists who are responsible for framing the content of the three application scenarios.

The project initiators were all CVCL colleagues and former colleagues, and the collegial ethos of CVCL and the unit's commitment has continued to be a mainstay in sustaining the resilience of CAVES through challenging and difficult times. The strength of institutional ties is extended through personal affiliations. The Video Lab representative admitted that his willingness to participate in the network and contribute his time on a voluntary basis had much to do with a strong emotional bond to UCT as his alma mater. In addition, the first MD of VIS was formerly a CVCL staff member, and a friend of the CAVES project leader. Team members from the different partners and sectoral backgrounds expressed high mutual respect for each other's professional competence.

One of the lessons that has emerged clearly is the importance of delineating distinct, complementary roles for the different partner organisations. The nature of such a project, in which exploratory research figures prominently, precludes the clear contracting that is a characteristic of more applied forms of research, where the dimensions of the technological challenge are more clearly known. In this sense, the early phases of the project necessarily involved intense negotiation around key strategic aims of the partners, roles, target markets for the final product, and even costs. The lack of finality was ascribed internally to the initiators' lack of project-management skills – an argument which seems to have some validity. It does, however, also arise from the nature of exploratory research, which involves indeterminacy and recursiveness.

'Expectations management' may be particularly significant in innovation projects, where the end product does not yet exist and has to be imagined. In such situations there is a danger that different partners may envisage very different outcomes, even if they appear to be talking about the same thing. For example, it became clear after a while that there was a mismatch between the expectations of CAMA, who wanted a fully formed virtual museum, and those of CVCL who intended to test and develop the VE technology in CAVES only 'up to a point', and had planned to raise further funds for developing specific applications at a later date.

Challenges: intellectual property rights and commercialisation

A key feature of CAVES is that neither of the enterprise partners in the network has demonstrated a substantive vested interest in the project. Nor have they contributed to it financially. Both enterprises have adopted a wait-and-see stance towards the project's innovation outcomes. The Video Lab representative has personally invested considerable time and energy, without any reimbursement to the company, because he believes that CAVES will succeed in its objectives and that the innovation may have significant potential for commercialisation in future. He intends that his participation will place Video Lab in a preferential position to acquire shares in any commercial venture that may evolve.

This issue is contentious, and an opposing view that rewards should be linked to consistent and demonstrable commitment has been expressed in the consortium. The team leader speculated that, in future projects, it would be better to allocate shares in any prospective commercial venture only to partners who have made a firm financial investment, and to students who work on the project. One possibility under discussion in 2003 was the establishment of a company to serve as custodian of the core intellectual property and the patenting of the methodology. The issue of intellectual property rights will be a point of contention if and when the commercialisation phase of the project is achieved.

It may be that the SME participants remain in sleeping-partner mode because they do not have the capital available, or because they are willing to mobilise resources only when the potential of the project is clearer – a risk-minimising approach. This could leave the project in a Catch-22 situation where development is fatally delayed – that is, overtaken by competing initiatives – or where there are not quite enough resources to take it through successive developments into a phase where commercialisation becomes assured. How to secure seamless funding is one of the major challenges facing the CAVES network, and will probably be a deciding factor in determining how full-scale applications are developed and products commercialised.

Another challenge for the project is obtaining appropriate talent for core programming work. The challenge of recruiting, developing and sustaining a pool of talent has been a major theme. Programming is a notoriously difficult occupational category to fill, especially in cutting-edge projects. Qualified professionals in the discipline are frequently lured into industry, not only locally, but also abroad. CVCL has not been able to withstand these pressures, and the project was adversely affected when two key staff members emigrated. Thus, CAVES as a cutting edge software development project is particularly vulnerable to drift of personnel and a resulting loss of continuity in its work schedule.

The team suffered the loss of a promising young black student through poaching of expertise between consortium members very early on. This incident contributed considerably to tensions between the academic partners, but serves to highlight the importance of fostering new talent with a view to the medium and long term. The importance attached to attracting and retaining good post-graduate students is a major expense driver. The project budget was set to cover very good student bursaries, which are much larger than the standard bursaries offered by UCT. Without these inducements, promising students are attracted into industry where they may not necessarily mature academically. A related point of dissension has been the high salaries that are paid to attract and retain good programmers.

Finally, an observation on project-management issues. The senior academic from CVCL estimated that the work involved in setting up and running CAVES has been equivalent to starting a small enterprise. The demanding nature of such an undertaking is, in his view, not adequately understood in the university, and combining such project work with normal academic duties – teaching and research – turned out to be an unmanageable load. This experience was the catalyst leading to the appointment of a professional project manager and underlines the importance of securing reliable project-management skills.

Case study 4: Multi-Sensor Microsatellite Imager (MSMI) project

The fourth case study focuses on the Multi-Sensor Microsatellite Imager (MSMI) project, which is a component of the much larger ZASat satellite programme. South African-developed satellites will be designed to supply affordable high-resolution imagery for use by African governments for monitoring, regulating, planning for, and managing resources (for example, water distribution, crop management, settlement infrastructure and disaster management) within their geographic areas of responsibility.

ZASat is a broad national initiative involving government, academic and research institutions and industry, for maintaining and increasing the momentum that has been built up in local satellite research and development. ZASat is exploratory in nature, involving many aspects of scientific and engineering research. The key players have agreed to work towards a common plan for a R200 million, five-year space technology programme in South Africa. The plan has three interconnected parts, each with its own sub-projects. These are: a space segment; a ground segment; and a technology segment, within which the MSMI is located.

Competition in the micro-satellite sector is strongly driven by specialised design. The weight of a satellite is related to its size, which determines its launching cost, so the smaller the satellite, the more affordable it is, and the more saleable are its components. The specific contribution of the MSMI project is to develop a smaller, and thus less costly, satellite imager payload than has been achieved internationally, which will still enable high resolution images to be captured for users. More specifically, the MSMI project is aimed at developing a high quality multi-sensor imager – or camera – that is affordable for the micro-satellite industry. The problem with imagers is that they either provide images on a scale that is useful for only a few limited applications, or that they are too expensive. Thus the central objective is to design an imager that can produce affordable high quality images and that is versatile enough to be widely applied.

The MSMI project is seen as central to convincing national and international interests of the merits of the ZASat programme. A versatile, high quality and affordable imager is potentially a major competitive advantage, and is likely to determine the success of ZASat.

Research and the space and micro-satellite industries in South Africa

Alongside the petro-chemicals, defence and nuclear industries, the space industry was a major recipient of research and development funding during the apartheid period, but just before 1994, the current government abruptly withdrew funding, and space industry programmes effectively collapsed. Nevertheless, the country still has space capacity in three areas – astronomy, earth observation and satellite communications. The industry does not have the capacity or funds to compete on the terrain of large satellites, but appears to enjoy a competitive advantage in relation to micro-satellites. The entire ZASat programme can be interpreted in the light of attempts to revive the micro-satellite industry and the research base on which it depends.

In a space programme, the benefits do not, in general, have an immediate commercial value. Hence, to be able to put together the critical mass for such a venture over a long time-span, a good relationship between academia and industry is essential. Space research is typically government funded. The benefits are only realised over a five- to ten-year period, and in general it is only governments that have the resource base to make such investments. The South African government is strongly committed to the peaceful use of space science and technology, and support for the re-energised satellite programme may come from several government sources. Likewise, because of the high cost of purchasing and operating a satellite system, the main clients are likely to be international, primarily government agencies and national military authorities. Competition is clearly global in nature but it is a potentially high-return industry. The micro-satellite sector is a high value-added business with a direct financial benefit, besides the spin-offs it generates in other areas of technology.

Construction of the network

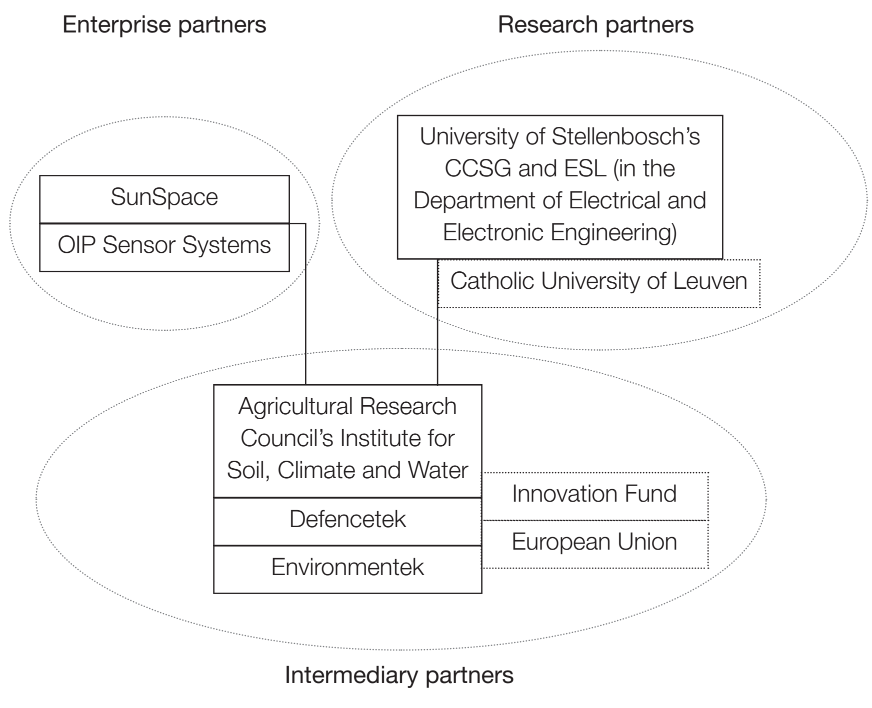
The MSMI network was constructed to fulfil the knowledge and engineering needs arising out of a complex research undertaking. The partners recruited were chosen to meet the requirements associated with qualifying for funding from the Innovation Fund. This network thus had to be constructed a priori to meet a time deadline specified by the tender process. As will be shown, there were pre-existing links between many of the different entities, with some being much stronger than others. Nevertheless, given the nature of the project, the network was not constituted in an evolutionary way.

The Innovation Fund proposal expected that the project would produce both an imager (physical artefact) and its applications (software and other products that facilitate the storage, manipulation and analysis of the data captured by the imager). The project of producing a prototype MSMI was conceived in two interrelated processes. This was because the development and actual design of the technologies – the physical remote-sensing system – had to be strongly informed by a clear understanding of what the needs of the eventual client were likely to be. In order to maximise the potential end-user benefits, reverse-engineering principles were considered imperative in the design. This logically required that the network should include participants who were already engaged in the complex process of analysing high-resolution satellite data across various spectral ranges. Techniques applied in the physical collection of data in space were understood to be logically inseparable from the context of application of the data by human analysts. Put differently, it was vital to involve enterprises with expertise in the use of existing applications and the development of new applications for the data collected through the MSMI. A successful integration of *technology development processes* and *applications processes* would produce the greatest sophistication and value-added benefits.

Accordingly, the partners have different functional roles, as reflected in Figure 3.4. In the technology development process, the participants are:

- The Department of Electrical and Electronic Engineering, University of Stellenbosch;
- SunSpace and Information Systems, a small private enterprise in South Africa;
- The Catholic University of Leuven, Belgium;
- OIP Sensor Systems, a private enterprise from Belgium; and
- Defencetek, a division of the Council for Scientific and Industrial Research.

Figure 3.4 The Multi-Sensor Microsatellite Imager network



In the applications development process there are two main participants:

- Environmentek, a unit within the CSIR; and
- The Institute for Soil, Climate and Water, a unit located within the Agricultural Research Council.

The technology development partners

SunSpace and Information Systems

The primary enterprise partner is SunSpace and Information Systems, an SME which has its origins in the work of academics in the Computer and Control Systems Group (CCSG) of the Department of Electrical and Electronic Engineering at Stellenbosch University. They began the SunSat project in 1992 with an intake of post-graduate students based in their Electronic Systems Laboratory (ESL). While negotiations were begun with NASA in 1994, SunSat was developed and manufactured almost entirely at Stellenbosch University, with input from the CSIR, and launched in the United States in 1999. Rapidly thereafter, commercial spinoffs evolved through the export of sub-systems from SunSat to Korea and Australia.

In the same period, the lead researchers from SunSat launched SunSpace and Information Systems as a company owned by Stellenbosch University to facilitate the commercialisation of intellectual capital originating in the university. The strategic moves made by Stellenbosch to provide a platform for commercialisation suggest an institution capable of strategically placing itself to maximise the benefits for academic researchers, and for the university itself. The capacity to act in an entrepreneurial way owes something to the history of the university, which has engaged in large-scale R&D project work in strategic and defence-related industries for some time.

SunSpace provides end-to-end services in the design and development of small and micro satellite systems. The flagship of their business is the SunSpace-180 satellite bus and there is also a range of satellite products. The enterprise can build internationally price-competitive micro and mini satellites because science, engineering and technical labour is relatively cheap in South Africa, and because they are not competing in the large-satellite market. The turnover of SunSpace is estimated to be R20 million per year, with a staff complement of fifty employees, including ten administration and support staff. Managers are brought in from industry to project-manage the company's systems. There is strong continuity in management, with the same core of personnel who launched the SunSat micro satellite system in the early 1990s still involved. A number of members of the team have dual roles as academic staff in the Department of Engineering and as directors of SunSpace.

SunSpace's mission emphasises innovation as central to its ability to remain competitive, and the company aims to, 'react with great flexibility to the needs of its clients' (see www.sunspace.co.za). SunSpace has strongly oriented itself to the international market and export. Its primary clients are international, and in this regard, it offers 'technology transfer partnerships' to international organisations. Research is essential to the business and R&D expenditure ranges from three to five per cent of turnover. In order to ensure that staff skills and expertise are allocated to revenue-producing projects, SunSpace contracts out research work. The company is located in Technopark Stellenbosch, and uses a number of other businesses located in the Technopark as consultants and sub-contractors. Thus SunSpace is prepared to exploit the value of geographical proximity and, importantly, is prepared to contract to local companies possessing the appropriate skills.

The evolution of SunSat has produced strong alliances between university staff in the CCSG, staff in the ESL and personnel in SunSpace. This can be simply represented in a value chain connecting the three entities, with the Computer and Control Systems Group conducting research, the Electronic Systems Laboratory undertaking development, and SunSpace manufacturing the commercial applications.

Computer and Control Systems Group (CCSG), Stellenbosch University

The CCSG, located in the Faculty of Engineering at Stellenbosch University, has three research groups covering biomedical electronics, computer systems and control systems. As can be seen, the CCSG, though historically linked to SunSat, does not only conduct work oriented to space applications. The focus area relevant to SunSat includes activities involving the development of advanced system simulators, non-linear system design, spacecraft and satellite control, and estimation techniques. This research group is developing an orientation control system for the SunSat micro-satellite.

Linkages with industry are considered fundamental to engineering research and, especially, to satellite research. It is common practice in the Stellenbosch Faculty of Engineering for academic staff to undertake contract work, either through the extended network of the group's clients, or through privately-owned close corporations. There are limited formal guidelines regulating privately commissioned work, an indication of the way in which the unwritten protocols work well. Partnerships and collaboration are thus central to the functioning of the CCSG. This is evidenced by the CCSG specifically establishing the Electronic Systems Laboratory (ESL) as a base for collaboration with industry, and to provide opportunities for post-graduate students and industry to become involved in joint developments of significant scale.

The researchers in the CCSG are highly qualified and much respected academics. Most came to academia after ten or more years in industry and are capable of working in multi-disciplinary environments. The CCSG has seven members of staff who supervise more than a dozen research students in the ESL.

OIP Sensor Systems

All the necessary technical research inputs could, naturally, not be obtained from within the CCSG and the ESL, thus requiring a complementary set of competencies from elsewhere. This was achieved through a link with the Catholic University of Leuven, in association with OIP Sensor Systems, also from Belgium. The connection was made possible through the framework of a bilateral agreement between the Belgian and South African governments.

OIP is a Belgian company with a long history in precision optics. It entered the space industry in the 1980s and specialises in design, development and manufacture of high-end opto-electronic components and systems for application in various space activities. The enterprise has extensive experience in the development of small cameras for satellites, and has developed a hyperspectral sensor for use on aircraft, which is to be adapted to space work on a small satellite. This is the core of their contribution to the programme.

Defencetek (Defence Technology)

Defencetek is a research division within the CSIR. The CSIR encourages industry partnerships, and is involved in substantial collaboration with higher education. Defencetek provides support for the South African Department of Defence, the National Defence Force, and the crime prevention establishment, through a wide range of facilities for testing, measuring and calibrating new electronics systems.

The Defence Electronics line programme at Defencetek has a 25-person Optronics Research Group, which is involved in the MSMI project. Their specific technological contribution is to develop the front end of the optics. In general, their primary role is design. The actual manufacture of the opto-mechanical components is outsourced and the Defencetek team conducts quality control, assembly, evaluation and testing. In this task they are building on their prior technology development experience. They offer SunSpace many years of experience in optical design, assembly and manufacture. This obviates the need for SunSpace to employ a specialised team.

The applications development partners

The aim of the applications development role is to include at least one research entity that can express user needs – to improve and extend potential end-user satisfaction. Reverse engineering is essential in such a high-risk and high-investment undertaking. Three entities were brought into the consortium, explicitly to specify the future uses of the satellite data for the imager design. For example, in designing the sensor system, the technology development partners would need specifications stating which wavebands the MSMI should be sensitive to, and be able to capture. An iterative process for refining specifications would then ensue in which a test would be done – perhaps by modelling – to establish how to engineer the required sensitivity in the imager and to assess how usable the data was.

Environmentek

The Environmentek (Water, Environment and Forestry Technology) Unit is located within the CSIR. It focuses on technologies for the environmental assessment and management of terrestrial resources, forestry, water resource management and coastal development. One of the key areas is 'spatial technologies', which includes remote sensing, Geographical Information Systems (GIS) and 3-D visualisation technology. Satellite imagery and aerial photographs are used to provide assessments of the natural resources of an area. There is a wide range of current initiatives and projects in the Spatial Technology Group that could involve high quality satellite-generated data. Their role in the MSMI network is determined by their interest in the applications of these spatial technologies to support environmental assessment and management.

Institute for Soil, Climate and Water (ISCW)

The Institute for Soil, Climate and Water (ISCW) is located within the Agricultural Research Council (ARC). The ARC is a national science council, organised to, 'promote the sustainable management and use of the agricultural natural resources through research, technology development, technology transfer and scientific services' (see www.arc.agric.za). Their clients are typically national departments monitoring primary resources, large corporates such as agricultural and forestry companies, development agencies, and NGOs.

The ISCW research programme on natural resources monitoring, auditing and impact assessment aims to develop, provide and operationalise technologies and systems for the monitoring and auditing of natural resources, and for assessing the impacts on these resources. The ISCW group active in MSMI is the Remote Sensing Group. They bring to the network their core capacity and interest in applications of satellite images in the service of monitoring natural resources. Three individuals participate, an electronic technician, a researcher, and the project manager. The Remote Sensing Group receives support from a CSIR geoinformatics division that provides remote-sensing capabilities.

Catholic University of Leuven

Researchers in the Laboratory of Forest, Nature and Landscape Research at the Catholic University of Leuven (CU Leuven) in Belgium, are developing, 'new methods to extract spatial information over forests and other ecosystems that may contribute to a better understanding and a sustainable management of these systems' (see www.sadl.kleueven.ac.be/lbh/lbnl/geomforeng/introGFE.htm). Their role is to collaborate with the optics engineers in the design of the imaging systems to maximise the usefulness of data captured in high-resolution satellite images. The multi-disciplinary team consists of fifteen researchers, including professorial, post-doctoral and, mainly, PhD students. This international partner is based in the Department of Land Management, in the Faculty of Agricultural and Applied Biological Sciences at CU Leuven. The unit has conducted research for the European Union and for Belgian and Flemish government agencies, and has links with universities in the USA and Canada.

Legal, technical and financial interactions of the MSMI network

Space research and the micro-satellite industry are small fields of expertise, characterised by a high degree of individual inter-connectivity. The point was made that the space sector is by definition trans-disciplinary, and that to build a satellite teams have to work across disciplinary boundaries.

Contractually, the network is relatively complex. On one level, contracts are required for the consortium co-ordination, between all the South African members, and with the Innovation Fund. There are two exceptions. The Belgian collaborators from CU Leuven, who have a contract with Stellenbosch University, also have a contract with OIP, their industrial partner, and both of these partners have a contract with the Flemish government funding agency. The Flemish government, through its Innovation Fund equivalent, has invested €1 million, of which three-quarters goes to OIP and one quarter to CU Leuven. The agreement with CU Leuven works at a number of levels – country to country, in terms of an international bilateral agreement between Belgium and South Africa, university to university, in terms of a co-operation agreement between the two universities, and a specific memorandum of understanding between CU Leuven and Stellenbosch University in relation to the MSMI project.

The second exception is with Defencetek, which is in effect a sub-contractor in a primary relationship with SunSpace, providing specialised expertise. Defencetek is not part of the Innovation Fund consortium, because of the role they play in relation to the South African National Defence Force. They cannot be affiliated to any local or international industry group as this may interfere with their role of advising government on matters relating to the strategic satellite industry.

With reference to the management of the network, SunSpace is the main technological development contractor, responsible for system engineering and project management on behalf of the consortium. This work is underwritten, entirely by the Innovation Fund, to the value of R14.8 million, and these resources are controlled by SunSpace, which is also responsible for ensuring that project elements are co-ordinated – the design, management and integration and testing of the camera. Their responsibility implies that they have to enforce specific time scales and budgets as if they are sub-contracting the work to the other parties. On the level of work authorisation, SunSpace as the main contractor controls sub-sets of the work to ensure that it is synchronised.

Each partner has a member on the steering committee responsible for managing relationships, financial decisions, signing off payments when obligations have been met, reporting risk management, project management, and so on. The role of a key individual, such as the project co-ordinator, as a driving force in establishing the network was repeatedly stressed.

It is clear that there is a technical network operating in parallel with the organisational network. Each member of the consortium has its own systems engineer or project manager to implement its own research schedule. These managers are expected to meet weekly, to discuss technical issues. For the technical network, SunSpace has been selected as the systems house, and their technical systems engineer acts as the technical interface.

The SunSpace technical systems engineer decides whether there is sufficient confidence in a specific research output, and whether it is mature enough to be incorporated into the project. This individual thus has technical power in the network. There is a potential tension between the project time scales managed by the project manager, the technical performance, managed by the technical systems engineer, and the funding, monitored by the project co-ordinator. It was foreseen that this could be a problem between members in the future.

Network interactions

Given that the network was in its early stages of operation at the time of research, the nature of communications and interaction is yet to be tested. However, the strongest pre-existing link between the partners is between the CCSG/ESL and SunSpace. This symbiotic relationship must be taken into account in comparative evaluation with other networks.

SunSpace sends some 80 per cent of its research needs to the CCSG, feeding significant funding into Stellenbosch University. When they identify a need for fundamental research to meet future commercial requirements of SunSpace, the university-based directors of SunSpace will often start research in the ESL before they have a commercial contract. SunSpace and ESL have learned that fundamental research can take an unexpected critical path, which requires a significant amount of time before it can inform projects. For this reason it is preferable for basic research to be completed prior to a contract.

SunSpace contracts out research to the ESL, with a plan of the subsystems required for the next few years, and funds ESL to research computer and control systems. The work of the ESL is a mixture of discovery-driven projects, particularly on the part of post-graduate students, and design-driven projects that are more commercially oriented to ensure the financial sustainability of the laboratory. Researchers and engineers work in the same lab because there is an appreciation of the importance of proximity in the exchange of tacit knowledge. This is believed to lower the costs of the development and production of the SunSat satellite programme.

It appears that tacit knowledge is invaluable for innovation in this company. However, it was reported that SunSpace tries hard to formalise knowledge, in the form of documentation of the design, and of any changes during the design process, to facilitate technology transfer. This is particularly important to keep tight configuration control over the engineering process.

A major challenge is to balance the functional flows between fundamental academic research in the CCSG-ESL and technology development by the commercial entity, SunSpace. Once conceptual, more fundamental, research from the university has been completed, SunSpace takes over the designs, or develops new components, some in-house, some at the university. Prototype designs produced by either consultants, researchers or post-graduate students do not necessarily fit the form and function of components required for space. Such products usually need to be repackaged for commercialisation by a SunSpace engineer with consultation from the academic side – which again points to the significance of tacit knowledge transfer.

The distinction is drawn in this network between, on the one hand, knowledge work which engages with new theory, new design, new technology and is conducted by academic researchers and postgraduate students, and, on the other hand, engineering work, which involves the application of good practice to systems design and integration, system testing, and project management, but does not necessarily contribute anything new to knowledge. Intellectual work has a high value but it has to be repackaged to be saleable. Thus there is a web of two-way relationships between SunSpace and Stellenbosch academics that sustains the technology transfer leap.

One limitation identified in the relationship between enterprise and the university is the danger that clients may perceive their work to be done by students, used as cheap labour, and not by professionals. It was seen as essential to have SunSpace staff in control of projects, but limiting student participation has a downside as it reduces capacity. The ESL thus initiated a new operational model in 2003, employing five engineers on a contract basis to complete development work and build specifically for prototype projects.

The issue of proximity in relation to this network is of interest. The main industry and higher education partners are in close geographical proximity in Stellenbosch. Indeed, as observed, there are some members of university staff that are part-time staff at SunSpace – including the leader of the ZASat programme. However, the application partners are both based at a distance in Pretoria, and the international partners are in Belgium. There are clear mechanisms and lines of communication to overcome distance, but this aspect will be tested as the project work kicks in.

Potential benefits and tensions

The project was at an early phase in 2003, which means that identification of benefits – tangible or intangible – can only be speculative. The major knowledge benefit envisaged is that industry and research organisations can stay at the cutting edge of technology. The immediate economic benefit of the project for the main industry partner, SunSpace, was expected to be engagement in new micro-satellite technology development, funded by the state through the Innovation Fund, and not out of it own profits. The advantages of the academic-industry link are important in marketing SunSpace products internationally. Academic status and credibility combine well with the ability of the enterprise to guarantee deliverables against a fixed-price contract.

The applications partners expressed appreciation for the perceived knowledge benefits of involvement – irrespective of the successful commercialisation of the product. ARC-ISCW envisaged a key benefit to be capacity development, through exposure to both academia and industry. It is important to bear this intangible benefit in mind in assessing the overall contributions of THRIP and IF funding.

Each set of players has its own agenda, and its own interpretation of the strategic goals for this project. For example, the Belgian partners are keen to prove their hypersensor sub-system in space, some partners want to use components developed in the project in other products, others want to promote their manufacturing capacity, and yet other partners want to develop their capacity to use the data for specific applications. This means that the collaborators are dependent on the project to achieve their needs, but some needs are almost tangential to the aims of the project. If not managed carefully, these differences may be accentuated as the project matures.

At the level of formal governance, the four main partners, SunSpace, the University of Stellenbosch, the CSIR and ARC are set to share in future profits, though the details were not clear at the time of the study. This is partly on account of the paradox of R&D work on a new product in its early phases, where, because of a range of factors (such as technology or market change) the financial rewards cannot be specified. As a result, the key issue in the early stages becomes ownership of the intellectual property rights, since this is the key to later accumulation. The consortium has an agreement on how to share the intellectual property. Each partner owns the rights to their work but they will register the new product jointly. The contract defines how ownership will be structured, and specifies how partners can decide whether to sell shares and so on. It was claimed that the partners would not sell the intellectual property for the MSMI, as a main aim is to develop South African intellectual property.

There was, however, considerable lack of clarity around the agreements between the partners, with potential for difficulties over the allocation of rights – for example, between the development and the application process owners. The timing of rewards is also important. It was argued that those who design and build the satellite will get more immediate financial benefits, but that the benefits for the applications partners will be more long term and sustainable, in terms of access to remote-sensing information obtained from space by MSMI and in terms of the economic benefits flowing from the project. These factors present a challenge of how to negotiate benefits and over what period.

ICT networks in South Africa

Patterns and trends of activity across the four cases are analysed in this section, to illustrate distinct issues significant to the creation of networks in the ICT sector in South Africa.

Determinants of network shape and dynamics

Origins of the networks
We have remarked that the research networks investigated here have different origins. In two instances – in the telecommunications sub-sector – higher education entities were approached by an enterprise with a quite specific knowledge gap that could be resolved only in a research environment, and this led to the establishment of new research relationships. In the other two cases, higher education entities approached enterprises to become involved in research to develop a new product or technology that had commercialisation potential, by initiating a consortium (CAVES and MSMI).

In all four of these cases, the networks were recipients of some form of government funding; networks established without government support are not discussed here. What the cases do illustrate is the key catalytic role played by government, and that the different funding mechanisms employed seem to affect how networks originate and take shape.

The CAVES and MSMI projects both were recipients of Innovation Fund support. The Innovation Fund offers relatively large-scale financial support and requires applicants to provide project plans with detailed evidence of competence and commitment from all research partners, according to a three-year operating cycle. This requires the prior formalisation of networks and contracts to meet time deadlines for proposal submission. The THRIP programme works on a shorter cycle and therefore activates funding more organically, based on applications that occur as the need or demand arises in the industry. Notwithstanding the likelihood that network partners would have had prior interaction, the 'artificiality' of big-bang Innovation Fund network creation may produce different outcomes from networks that develop more organically.

We have observed that the Innovation Fund financed MSMI network was indeed built on a number of strong prior contacts. The case study evidence corroborates Benassi's finding that 'long-term personal knowledge between key actors ignites co-operative relations in a large proportion of strategic alliances' (1993: 105). The great advantage of relying on prior relationships is foreknowledge of the prospective partners' trustworthiness – or otherwise. There are, however, different gradations of familiarity based on prior collaboration, which the MSMI network clearly reveals. The two primary organisations involved are a higher education institution and its own spin-off enterprise, owned by the university, which further emphasises the power of this formal relationship. On the other hand, the network also contains partners that were brought together through the medium of prior interpersonal research links. The relative strength of such prior relationships can shape the nature of the network interaction.

Research and development networks cannot always be based on prior experience and trust. Marschan-Piekkari, Macdonald and Assimakopoulos (2001: 68) observe, with reference to some government programmes that, 'in the desperate search for appropriate partners, the requirement that collaboration facilitate innovation gives way to the requirement that collaboration serve political and pragmatic purposes.' This is an important observation that can drive further analysis of how networks are formed outside of the 'comfort zone' of prior relationships.

Network size and involvement of participants

The size of a network is an important characteristic. Size in terms of number of partners may be influenced by the complexity of the research challenge, the prescriptions of funders, or the availability of potential partners. The number of partners – and their selection – will also be influenced by the size of the sector in terms of the number of enterprises with the required expertise, and whether enterprises in the sector have evolved towards specialisation, or towards a business model integrating several business activities or processes within a single enterprise. The number of partners in the four cases surveyed ranged from three to eight. Network size is not necessarily fixed but can fluctuate – as revealed in the CAVES case, in which two potentially significant research partners withdrew at a relatively early stage. Networks can presumably increase in size to draw in necessary expertise or research capability, or to substitute or replace partners over time, although the cases investigated here do not show this occurring.

The case studies shed light on the conjecture that the nature of a research problem might have an influence on the form of the corresponding network. In the optical fibre and FSO cases, both of which address strictly applied research problems, the networks are small. The MSMI and the CAVES projects both have a strong basic research component, which must ultimately feed into a product with multiple applications. The MSMI currently has a large network, and the CAVES project has shrunk from the larger network base originally planned.

The CAVES and MSMI networks inserted a research dimension that took account of client or user needs, but which made the project network larger. In respect of role allocation, an extremely important strategic decision was undertaken to include partners who could inform development from a user perspective. The concept of 'user-led innovation' or 'co-invention' has been a powerful driver of accelerated innovation in the software industry (Mowery 2003: 304). In these cases, specific partners focused on the design elements relevant to the application of the technologies to contexts of use (for example, users of virtual environment software and consumers of satellite data). The application side involved working with real data that would populate the systems infrastructure (hardware and software) to test how well the product being designed could work.

In contrast, the applied project networks did not include additional research partners to take account of the applications dimension, which was articulated directly by the enterprise initiator and partner. This reinforces the suggestion that basic (and applied) R&D networks may be larger than (strictly) applied R&D networks. This is because with an exploratory R&D challenge it is strategically valuable for an organisation to be brought into the network to articulate and explore potential user needs, whereas in an applied case, it is actually the 'user' or client who is integrally involved in commissioning and driving the research, thus ruling out the need for a third party.

It became apparent that in addition to full-time higher education and enterprise employees and students, there were significant numbers of independent contractors involved in three of the projects. This may especially be the case in the ICT domain, since the IT – and especially the programming industry – has a large population of independent workers. The FSO case was particularly interesting because F'Satie/Incentif was deliberately designed to make a pool of individual consultants available to the member SMEs. The population of independent consultants did not receive specific attention in the case studies, but their presence deserves further analysis, as contract employment at high levels of expertise is a characteristic of the network society (Marsden 2004: 2–4).

Power dynamics and the distribution of management roles in the network

A complex challenge is to make sense of the ways in which authority, power and control are exerted in the different network formations. A scan across the cases with reference to the core project-management roles – management of funding, management of the project, and management of research – reveals that in three of the four cases, all management roles are assumed by a single organisation, either a higher education institution (two cases), or an enterprise (two cases). This appears to demonstrate that neither enterprise nor higher education nodes consistently dominate, but it does suggest that there is likely to be an uneven balance of power. That unequal distribution of power and control is to be expected and is not necessarily negative; as Grabher (1993) observes: power and asymmetry of interdependencies have a functional element in networks.

The dynamics producing such asymmetries are revealed in the histories of the networks. The analysis shows that within each network there is a pattern of allocating power, role and responsibility in the initiation phase, and that, over time, there are shifts in the articulation of power and responsibility. For example, we know that, in the CAVES case, the enterprise partners showed little commitment to the project and thus, by default, all the core-management roles fell onto the higher education node. The case studies seem to suggest that R&D projects that are 'applied' in nature are more focused and less complex, and therefore tend to be more stable than the projects that involve a higher level of fundamental research.

The allocation of funding management is more likely to be located in a higher education institution because the Innovation Fund and THRIP favour them as conduits for distributing funding. However, funding-management activities may not necessarily be conducted by the research entity itself. This depends on the level of devolution of financial authority permissible within the rules of the institution. This study showed that a research unit in a higher education institution involved in a research network can be restricted by the institution's financial structures and processes. The separation of the research and funding-management functions proved problematic in at least one case. In contrast, the CVCL unit at UCT could not make major financial decisions outside of the formal university decision hierarchy because the institution's systems were not flexible enough. The important issue here is the degree to which higher education institutions will be willing to free up research units so that they can operate more entrepreneurially and more flexibly.

The analysis showed that partners tend to fulfil different functions with differing levels of involvement. In the larger networks, there is a more complex division of labour where particular research tasks or functions are sub-specified and these functions or tasks will in turn involve greater or lesser involvement in terms of time, cost and centrality to the aims of the project. For example, funders – government intermediaries – tend to become passive once a project is initiated and step in only if it seems to be in serious jeopardy.

There are clear difficulties in judging the intensity of involvement over time of partners with different functions. It is nevertheless important to identify which are the partners with higher activity levels and greater functional participation in the research – from knowledge generation, to application and finally to dissemination. In a large network there may be only a small core of organisations consistently engaged across all of the research phases and network activities. If this is not acknowledged, any analysis is in danger of exaggerating network dimensions. In each case study, the number of research partners with higher knowledge-related activity levels was less than the total number in the network. The MSMI project is the largest, and also has the highest proportion of partners with integral contributions to make to the project as a whole. In contrast, the Optical Fibre, FSO and CAVES projects have two main active partners involved directly in research (out of five formal participants) although this is for different reasons, as the case studies illustrate.

Spatial proximity, knowledge transfer and communication

The spatial proximity of partners is a factor that can profoundly affect the nature of network interaction, whether this involves the communication of research knowledge or management information. It is observable that the core research participants in every project are located in a compact distribution in or near the same urban centre: Port Elizabeth, Pretoria or Stellenbosch. At the outset, the Optical Fibre and CAVES networks both had partners at a distance, but over time, the isolated partners dropped out. This suggests that proximity is likely to be a potent factor influencing the success of networks. Cantwell and Santangelo (1999) suggest that the tendency of enterprise networks to cluster spatially is related to the density of tacit knowledge transfer between participants.

The MSMI project involves international collaboration. It remains to be seen how well ICT-based communications can compensate for spatially dispersed networks. The application of ICT may potentially sustain research work between partners, but the use of ICT does seem to require proactive changes in work practices (Howells 1995: 180), and will involve testing the extent to which, especially, tacit knowledge forms can be exchanged via electronic media (Bolisani and Scarso 1999: 216).

The role of participants at each node

The shifting concept of 'nodes' as applied to higher education partners

Based on the ICT cases, the concept of nodes within the network can be elaborated, to take account of the complex ways in which the participants functioned. This claim is based on two observations. First, not all of the cases involved a partnership between a higher education entity and an enterprise, and second, institutions adopted roles that did not necessarily coincide with their assumed function, given their nodal position.

For example, the CAVES case reveals that on account of a wait-and-see stance from two enterprises, the core partners are both located *within* the University of Cape Town. On this basis, the status of this case as an example of a functioning network between higher education and industry partners is debatable. However, the situation is more complex, in that CAMA acts as a form of client and a potential user of the software product under development. As such, CAMA's role can be conceived of as a client enterprise in terms of its contribution to the R&D process. This case reveals how the intended roles and functions defined at the inception of networks can change over time, and will ultimately reveal who the core partners really are. It can be argued that although CAVES was formally structured as a network consortium, in practice the partnership did not function as a network.

The FSO network is quite different because two enterprises are the core participants in the research process itself. The higher education partner, F'Satie/Incentif operates as a broker or facilitator, rather than as a research partner. This is especially important in an economic context where nascent R&D capacity needs to be encouraged by establishing a facilitative environment. In this instance, F'Satie/Incentif is not operating as a research entity and could be classified as an intermediary institution that provides infrastructural support. F'Satie could be seen as an active intermediary, as opposed to a government funding scheme which would act as a passive intermediary.

The fact that there is no higher education partner with significant involvement in the FSO research process suggests that this, too, is not a 'typical network'. Indeed, this may be classified as an exemplary case of an incentivised partnership, acting as a proto-network (see Figure 1.1). Kruss (2005) proposes that the new incentivised forms of partnership, stimulated by government funding aimed at developing R&D and innovative capacity in South Africa, are characterised by weak forms of collaboration. The research is usually applied, developmental or strategic and, alongside intellectual motivations, there is a strong financial motivation on the part of higher education institutions to pursue partnership. The motivation for industry is primarily intellectual, to meet its knowledge needs, to have research done with government financial support. In this case, THRIP funding was reinforced by bilateral French-South African government funds.

Thus, in only two of the four cases can we observe with some confidence that a technology co-operation network operates between higher education and enterprise participants. In the other two cases, higher education is largely a facilitator – as in the FSO project – or, in practice if not in intent, a sole driver of the project, as in the CAVES project.

The historical origins of the higher education partners compounds the complexity in defining the higher education node, because there are significant differences between the universities and technikons involved. The major difference can be found between those institutions that developed as research institutions and those that developed as teaching institutions. The factors leading to this functional division lie in the history of higher education under apartheid, where research capacity was built in the older white English and Afrikaans language universities, such as those involved in the CAVES and the MSMI projects, both of which have a strong basic or fundamental research orientation. In contrast, the other two cases – FSO and Optical Fibre – are both examples of applied research and development. Significantly, the FSO is based in a technikon, and the Optical Fibre project in a newer university, whose role under apartheid was as a teaching institution. These cases highlight the significant differences between institutions in the extent to which they have sufficient accumulated experience to support networks.

Government as a source of funding and of R&D expertise
The role of government has been presented here largely as an intermediary stakeholder. The injection of capital into R&D activities, especially through the Innovation Fund and THRIP, was shown as being an important mechanism for incentivising private enterprises to match government commitments, and as a key source of finance for small technology-based firms (Romijn and Albaladejo 2002). The MSMI project is an example of an international R&D network that receives funding in more than one national context, and the FSO partnership, too, receives funding arising out of bilateral governmental agreements. This raises questions about the levels of co-ordination of national and international or regional bodies in respect to obtaining the most efficient and effective articulation of funding systems.

The case studies highlight an additional valuable facet of government involvement – the contribution of statutory national science councils. Notably, evidence of such involvement by the CSIR is mainly associated with Innovation Fund-supported projects that are large-scale and heavily funded. In the case of the MSMI project, the CSIR and the Agricultural Research Council are engaged in the project primarily as research entities, strategically contributing to the scientific value of the project. This indicates that government involvement can extend beyond funding towards injecting state-sponsored research expertise into the country's R&D system. It is probable that the pressure on statutory science councils to generate income in their own right has contributed to their willingness to engage in research relationships with private sector enterprises. This means that science councils which link into networks as research-driven entities cannot be understood simply as having an intermediary function. Rather, they can also be analysed in terms of their contribution to the networks in the guise, if not as profit-seeking, then at least as cost-recovering entities.

The outcomes – students and intellectual property

Human resources, work experience and training
Given that human resources lie at the core of R&D activities and are central to higher education's function, it is not surprising that the training of students and enterprise staff, as well as the involvement of post-graduate students in research, was a key theme. Most students were based in higher education laboratories rather than in the laboratories and workspaces of enterprises. In some instances, enterprises expressed concerns about the involvement of students. Mechanisms were, however, found for dealing with quality-assuring the student work, and assuring clients that project work was not simply being farmed out to students on an indiscriminate basis.

Research and development continuity is heavily dependent on the movement of new scientists into networks. The CAVES case pointed to serious problems with sustaining research productivity because of losses of senior post-graduate students who were significant contributors to the project. The cut-throat competition for high-level expertise in ICT was clearly a factor. These issues were not as severe in the MSMI case, which was larger in scale but also seemed to have created opportunities for student experience and income opportunities.

Where students are involved in research activities, an important secondary product is the 'production' of the students themselves. Consequently, the research networks can be seen as nursery environments in which to grow high-level human resources. In the Optical Fibre case, this expectation was clearly articulated and the enterprise sent employees into the higher education institution for upskilling. This suggests that the establishment of a research programme was a good strategy for having an indirect influence on the training of prospective employees.

Intellectual property rights
One of the major challenges for the networks was how to organise the distribution of rewards, in particular, intellectual property rights ownership. This was especially the case for the larger, more discovery-driven and less applied networks, where the product or service has as yet unknown characteristics. It is thus difficult to quantify value and, by corollary, to apportion rewards to participants. Nevertheless, the projects were all subject to risks of 'approbriability' (or ease with which competitors can imitate innovation) and of 'competence destruction' (or volatility and uncertainty of technological development). These two factors directly influence the window of time in which the owners of the new products or processes can generate revenues, and will influence how enterprises manage their innovative products or services. In all of the cases, the evolving nature of technology and its effects on approbriability and competence destruction were evident.

One way of reducing approbriability is to embed the product or service within a large value-adding service framework, bundling it as part of a larger service package, and also making it customer specific (Casper and Whitley 2004: 91). The MSMI and the Optical Fibre partners were engaged in such processes, which could be expected to extend profitability.

The ICT case studies and the future of networks

The ICT cases observed here were limited by time – partly the timescale of their funding and partly the time required to complete this research project. The life cycle of a research network needs to be examined in broader temporal terms, by considering how it contributes to future networking.

The cases examined suggest that the reciprocity of exchange relations, which Grabher (1993) identifies as a feature of a network, is something that evolves with familiarity over time. Network modelling theory suggests that market and technological externalities play an important role in driving the emergence of denser networks. As the network matures it becomes denser and denser, and the unequal distribution of links is eliminated. In effect, firms that are not able to insert themselves in the network, or that occupy weak positions in the network, will be forced out of the market. This process of 'densification' in the long run, 'levels out the differences among the surviving firms' (Zirulia 2004: 32).

The small size and uneven distribution of network links observed here suggest that network evolution in ICT-based R&D industry in South Africa as a whole is relatively immature. Indeed, not all the cases may be described as networks, either in their design or by default as they have developed in practice. If R&D network evolution serves over time as a 'selection mechanism' (Zirulia 2004: 32), it will be important to observe not only the life-cycle of the current existing network cases but also the extent to which currently networked firms become linked to other new networks in the future. It is important to note that not only is the stage of evolution in a specific network of concern, but that the cases must be understood in relation to the stage of development of *networking* in the entire industry.

CHAPTER 4

Partnerships and networks in new materials development

Shane Godfrey

The new materials technology field

Materials are important for almost every human activity and new materials development (NMD) has been critical in the technological advances made by society. New materials are vital for current economic development and competitiveness, particularly in the manufacturing sector, as they are the basis for all product technologies. It is not surprising therefore that advanced industrialised nations view NMD as a key strategic research area. Recent developments in new materials, which emphasise their applications and approach NMD as a sub-set of integrated manufacture, have accentuated the importance of this technology field and the need for high-level research in the area.[1]

A generic definition of new materials is, 'material types (or matter) that are different from existing well characterised substances' (Knutsen 2002: 1). However, recent developments in NMD require additions to this definition. Increasingly, NMD is being driven not by the search for entirely novel materials, but by the discovery of new applications for existing materials. The focus of such innovation is therefore on the development of new processing techniques, although the emphasis on applications is also leading to the development of new materials as an incidental part of the process of designing and implementing new applications. For instance, research into artery replacement in the biomedical field involves the development of special, and new, polymers. This has led Knutsen (2002: 1) to argue for an expanded definition to include, 'existing materials that will find broader, and sometimes very critical, application as a result of the development of new processing techniques' and, 'new or modified materials whose development may be incidental to the design and successful implementation of a new application'. It is in the latter two areas that most current research on new materials in South Africa is primarily concentrated.

One of the difficulties in encapsulating and understanding the NMD field arises from the way in which it cuts across traditional industrial sectors (as well as other technology fields). This is particularly the case in recent times with the development of engineered materials (such as superalloys, laminates and composites, advanced ceramics, and electronic materials). Knutsen (2002: 6) characterises this development as a shift, 'from using materials as they occur in nature to using custom or engineered materials that are synthesised into particular states or forms to meet particular needs in quantities only necessary to meet the need'. As an example of the diversity of applications of new materials, key areas in which new materials development is taking place are:

- Biomaterials (such as materials that are used to replace or restore function to a body tissue);

1 This chapter is based on case studies conducted by Gilton Klerck, Wendy Annecke and Candice Harrison, and this section draws heavily on an analytical and historical overview of the field in South Africa prepared by Knutsen (2002).

- Nanomaterials (which examines the changes in the properties and behaviour of materials at the nano-level,[2] with applications in fields such as magnetic information storage and micro-lasing that could replace wires with optical interconnections);
- Materials for the power industry (mainly driven by the search for 'clean' power, with the main routes being nuclear power and renewable energy sources, both of which require new materials applications); and
- Building materials (the need to make appropriate construction materials available and affordable to all parts of the world, as well as developing locally available materials that will provide shelter and comfort).

Knutsen suggests that a challenge facing the NMD technology field is the energy efficiency of new materials (both in their production and as products), as well as their reliability, affordability and impact on the environment.

The NMD technology field in South Africa

Historically, in South Africa, the NMD field had its roots in the mining industry, for long the main generator of economic growth in the country. Challenges to apartheid internally and externally meant that from about the 1970s NMD was strongly influenced by political considerations: the main driving force was the military, as well as the goals of energy self-sufficiency and food security. There were substantial investments in strategic industries, such as ARMSCOR (weapons), SASOL (oil from coal), ISCOR (steel), the Atomic Energy Corporation (nuclear power), and in the agricultural sciences. The intensification of economic sanctions in the 1980s gave renewed impetus to the existing industrial policy of import substitution. This widened the range of products in which self-sufficiency was sought. The 1970s saw NMD playing a key role in the mining and ferro-alloys sectors, with fundamental studies being conducted on alloys, new battery systems (as a result of the oil crisis), ceramics, and electronic materials. In the 1980s there was increasing demand from the defence sector for advanced materials, and for design and processing capabilities, as well as a wider demand for materials engineering, materials processing and applications knowledge.

Political change in South Africa from 1994 saw much of the rationale for the existing structure of the NMD technology field disappear, while reintegration into the global economy has thrown up new challenges and research avenues. The country is, however, struggling to face those challenges. The downgrading of the strategic importance of NMD as political change gained momentum has eroded research capacity in the field, and the research community is far less cohesive than it was in the past. Knutsen describes the state of new materials research in South Africa as 'fragmented', a view that was borne out in interviews conducted with key university-based scientists in the field (2002: 22).

This change is not only a consequence of new political priorities. The downturn in the gold mining industry has seen a contraction in funding for research on NMD at higher education institutions. Research has also been affected by the downsizing of industrial research and development (R&D) activity. Many firms now find it easier and cheaper to acquire technology from overseas. This is particularly the case where local firms have become part of multi-national corporations that have their R&D facilities offshore.

2 Nanomaterials are new materials, created in the laboratory, at molecular level.

Such developments have impacted on the state of NMD research at higher education institutions as well as on links with industry.[3]

NMD research in relation to government policy

Besides being fragmented, the scale of new materials research in South Africa has diminished substantially since the early 1990s.[4] There are nevertheless strong pockets of research at a number of universities, mainly those with engineering faculties: the University of the Witwatersrand, the University of Cape Town, Stellenbosch University, Pretoria University, Natal University, Potchefstroom University, and the University of the Western Cape. Research in new materials is also being conducted at what were then Port Elizabeth Technikon, Technikon Natal, Technikon Pretoria, Technikon Witwatersrand, and the Cape Technikon.[5]

A brief survey of the THRIP partnerships in NMD, and evidence from interviews with key researchers at these institutions, indicates that research is still driven by very large firms or organisations, such as Sasol, Element Six (previously De Beers), Kentron (previously Denel), Plascon Paints, Mondi, Eskom, Iscor, Kumba Resources, Grinaker, Pretoria Portland Cements, Telkom, and Anglo Platinum. The THRIP-funded projects typically range across most of the key areas of new materials research: aluminium and stainless steel technology, automotive alloys, concrete materials technology, building materials made from waste, carbons for pebble bed nuclear reactors, nanomaterials technology, polymeric materials, polymer additives, starch-based polymers, ceramic composites, acid battery technology, and optical communications.

Despite these pockets of expertise, the prevailing view amongst university-based researchers is that research in the field is in a poor state. This is confirmed when one compares the number of researchers who have published in the field in the last five years or who have received a National Research Foundation (NRF) grant, or a THRIP or Innovation Fund grant. An HSRC 2003 database showed that the number of researchers in the biotechnology and ICT fields exceeds that in the NMD field. NMD researchers made up only 22 per cent (212 researchers) of the total. There are fewer researchers involved in THRIP and IF projects in the NMD field than in the biotechnology and ICT fields: in 2002 159 researchers in new materials as opposed to 211 in ICT and 294 in biotechnology.[6] However, the total number of projects in new materials compares favourably with the other two technology fields, as does total expenditure on these projects. Project outputs in the NMD field (777) are slightly more than in biotechnology (750), with ICT well ahead of both (948) (HSRC 2003).

3 The restructuring undergone by the Council for Scientific and Industrial Research (CSIR) is indicative of the broader shifts in the NMD technology field. In the mid-1980s the CSIR consolidated its materials science research through the formation of its 'MATTEK' division. This was followed by the emergence of a number of strong networks involving ARMSCOR and other key industries, as well as a number of local universities. The areas of research covered by the networks were high performance alloys, polymers, ceramics and composite materials. After 1994 most of the research activities of MATTEK were relocated to the Manufacturing and Materials Technology business unit. Along with the restructuring went a shift in focus from materials research to application-based research and manufacturing technology (Knutsen, 2002: 21).

4 This section benefited from interviews conducted with Associate Professor R Knutsen, University of Cape Town, Professor R Sanderson, Polymer Institute, Stellenbosch University and Professor V Verijenko, Centre for Composite Materials, Natal University.

5 We use here the names of the institutions as they were at the time of the survey – before the restructuring process finalised in 2005 which has changed the entire higher education landscape.

6 The research used multiple measures: researchers may have had an NRF grant and a THRIP grant, and may also have published.

These somewhat mixed indicators of the health of the NMD field correspond to international trends. Research by Hagedoorn (1993), in which a database of 10 000 strategic alliances was analysed, showed that in the 1980s about 70 per cent of alliances were in the fields of ICT, biotechnology and NMD. However, NMD made up only 10.3 per cent, compared to biotechnology at 20.2 per cent and ICT at 41.2 per cent. But by the late 1980s this appeared to be changing. Growth of strategic alliances in the period 1985–1989 was strongest in the new materials field (by a factor of about 2.5), compared to ICT and biotechnology (both about 1.7).

There are indications that more recent developments with regard to science and technology policy, as well as industrial policy, could halt the apparent decline of new materials research, which may prove to have been a temporary phenomenon. The National Research and Development Strategy aims to create a generally supportive climate to enhance the development, organisation and utilisation of technology resources (DACST 2002a). The Integrated Manufacturing Strategy, developed by the Department of Trade and Industry, focuses on enhancing the competitiveness of the manufacturing sector, emphasising the need to compete increasingly on the basis of innovation and knowledge-intensive goods and services (DTI 2002). These goals are given more substance, including specifically in relation to new materials, in the proposals of the national Advanced Manufacturing Technology Strategy (AMTS), initiated under the National Advisory Council on Innovation in 2003.

The AMTS aims to stimulate technological upgrading and build a supportive environment for innovation, through enhancing the supply of skilled manpower, technology infrastructure and funds. It will focus on priority sectors – drawn mainly from those targeted by the Integrated Manufacturing Strategy – such as the automotive (and transport) sectors, cultural/craft industries, clothing and textiles, metals (and minerals), and chemicals. Simultaneously, it identifies cross-cutting 'technology focus areas' such as advanced materials, cleaner production technologies and ICT in manufacturing (AMTS 2003 Vol 1). The sectors and technology focus areas are organised in the form of a matrix. This approach is critical for the AMTS: the aim will be to develop the synergies that exist between sectors and technology focus areas, rather than to focus narrowly on one or the other. In this way, the strategy is directed at overcoming the, 'fragmentation, silo mode approaches and…lack of resources' that currently characterise South Africa's innovation system.

It is evident that new materials development will be a critical target area for the AMTS, particularly in the technology focus area of advanced materials, which overlaps – to a greater or lesser extent – with other technology focus areas (such as product technologies), and cuts across a range of the targeted industrial sectors such as metals (and minerals), and chemicals. The AMTS has furthermore identified a number of existing 'Innovation Networks' – with either a sectoral or technology focus area bias – which it targets for specific support. For example, an Advanced Materials Network will focus on new product development, material beneficiation and improved production and manufacturing systems, through the commercialisation of scientific research. The initial focus will be on nanomaterials, advanced polymers and ceramics, and high performance materials based on natural resources (including minerals), as well as aspects of 'smart' materials, biomaterials and composites. This Advanced Metals Network will aim to improve competitiveness in the carbon steel, stainless steel, light metals and alloys, and precious metals sectors. The applications would, in the main, impact on the automotive, aerospace, household products, building and construction, jewellery, mining, and packaging industries. A third relevant network that is under consideration is a Chemical

Industry Network that could focus on process technology and platform skills, including amongst others, catalysis, synthesis, extraction and computational technology.

The AMTS initiative, if managed effectively, could result in an increase in new materials research and innovation in the future, and greater strategic co-ordination of research efforts, to overcome fragmentation. Significantly, the network cases that will be analysed in this chapter fall in the minerals, packaging, and chemical industries, involving advanced polymer, extraction and catalysis technologies, which are the target of particular attention in the AMTS. However, at the time of the research, shifts in priorities and funding meant that partnerships existed in isolation, and this recent development of a substantial strategic initiative on the part of government had yet to be implemented.

Secrecy

This history describes an aspect of the new materials development field that distinguishes it from the biotechnology and ICT fields. A high degree of secrecy surrounds research and innovation in the NMD field, which highlights key features of the field and the industries with which it intersects. For instance, this strong concern with secrecy and confidentiality made it difficult to negotiate participation in the research. Some companies did not even want it known that they are undertaking research in that particular area, while others did not want to provide anything more than a brief general description of the nature of the product or process being researched.

At the heart of the matter lies the nature of competition in the field, which is underpinned by the maturity of the NMD technology field, the size of firms operating in the field, and the potential returns on research investment.[7] First, it is argued that new materials is a more mature field than biotechnology and ICT, which was described as 'pre-competitive'. Innovation in new materials is seen as having an immediate impact on competitiveness in the market, whereas this is not yet the case in the other two fields. A second related reason is the size of the firms involved. A few firms in South Africa dominate in the related industrial sectors, and most are also major world players. Historically, they have had the capital to build significant R&D capacity as well as develop innovative technologies in-house. They reportedly tend to view themselves as 'knowledge firms', and their culture has therefore been to 'grow their own knowledge' rather than to 'buy in' knowledge. Consequently, they have become extremely protective of such knowledge.

Third, while the large firms that exploit new materials development have the capital to invest in research, the potential returns on this research are enormous. A typical claim was that the cutting-edge research currently being conducted in new materials could in a few years fundamentally change our world and the way we live. Because the returns are potentially significant, there is an equivalent level of secrecy to protect proprietary knowledge. While the potential impact may also hold true for biotechnology and ICT research, the industrial infrastructure does not exist to commercialise innovations to the extent that it does in the NMD field, and therefore allows greater openness.

A final factor to consider is the political history of the new materials field. Its roots in the mining industry and its strong links with industries and firms (particularly the arms industry), seen by the apartheid regime as strategic priorities, has had considerable impact on the culture of the research community.

7 This argument has been constructed largely on the basis of interviews conducted with three senior academics in the new materials field, in different institutions.

An examination of the processes at the heart of the networks in relation to industrial sectors and markets will further illuminate such dynamics.

Process, sector and market: the position of industry partners

The dominance of the industrial sectors by very large firms, the concern with secrecy around proprietary knowledge, the fragmented nature of research, and the existence of pockets of expertise in the new materials field have been highlighted. Against these general trends, a detailed consideration of the specific industrial process at the heart of research and development in each network will be considered. Examination of the specific industrial sectors and markets within which an industry partner operates, will illustrate how this influences the nature of a network. A case-by-case approach will be followed, after which common trends will be drawn out.

The electro-chemical recovery of metals partnership

The impact of secrecy around proprietary knowledge was particularly evident in the electro-chemical recovery of metals partnership.[8] The research project focused on the development of technology in the area of platinum group metals (PGMs)[9] recovery, which involved, on the one hand, the development of a process (chemical engineering aspect), and on the other hand, the development of a product (electro-chemistry aspect). This was directed at upgrading the quality of the ores being mined. It was stated that the intention of the research would be to 'shorten the pipeline' and make the recovery process more cost-effective. The industry partner, Anglo Platinum, stressed that the research was focused on the improvement of existing technology:

> The process has been used for years by other PGMs producers and Anglo Platinum had done work on it in the past, albeit with mixed results. The difference is that we have commissioned Wits to use a fundamental approach in their investigation to ensure we have better understanding of the process, so that if we apply the process we can be assured that deviations from set parameters will be understood and appropriate corrective action can be taken. (Interview: industry partner)

While the AMTS for the metals and minerals sector seek to shift the emphasis to the downstream applications of platinum, this partnership deals with an upstream activity, with the primary aim being greater cost efficiency. The reason for this lies in the difficulty of the recovery process for PGMs. The mining of PGMs tends to be easier and significantly safer than gold mining, since the reefs are generally shallower and rock formations more stable, but the complexity of PGMs mineralogy makes them difficult and thus relatively expensive to recover.

The reason why Anglo Platinum is reconsidering the upgrading process appears to be due in part to their access to electro-chemical expertise. Electro-chemistry deals with chemical reactions involving electricity and is employed in many industrial processes (such as the manufacture of chlorine and the extraction of aluminium). South Africa has minimal electro-chemical expertise (partly because of the 'brain drain'), and depends to a large extent on the importation of products, usually at a high premium. One of the pockets of

8 This made interpretation of the limited information provided a challenging task for the researcher, a caution that should be borne in mind throughout.
9 The PGMs are platinum, palladium, rhodium, ruthenium, iridium and osmium.

expertise in electro-chemistry is the Centre for Electro-Chemistry at the University of the Witwatersrand. Besides access to expertise, Anglo Platinum established a link with this Centre because of fierce competition in the sector, in which firms are constantly searching for advantage, either through improved processing or new technology.

Mining and minerals have long been the backbone of the South African economy, but parts of the industry, particularly the gold-mining sector, have been in decline in recent years. An exception is the platinum sector, which has faced a relatively buoyant market. South Africa has 80 per cent of the world's proven ore reserves and is the major supplier of platinum to the world market (4 080 000 ounces annually). This brings the country R34 billion annually in foreign exchange earnings and sustains about 90 000 jobs. Platinum has a wide variety of applications, but demand is driven mainly by jewellery (43.6 per cent) and auto catalysts (30.6 per cent), with the remainder spread across the chemical industry, the electrical and electronics sector, the glass manufacturing industry, and the petroleum industry. The highest demands are from Europe and Japan (AMTS 2003 Vol 2: 63 and 80).

Anglo Platinum is the world's leading producer of platinum: South Africa supplies 73 per cent of the global market needs, and Anglo Platinum produces more than half of that. The firm exploits the richest known reserve of PGMs (known as the Bushveld Igneous Complex). Research is vital for competitiveness in the sector. Any improvement to the recovery process would be quickly commercialised and could have a significant impact on the profitability of the company. The returns are potentially vast: Anglo Platinum's earnings for the year ending 2002 were R5 630 million. The need to optimise the recovery process is linked to the firm's expansion plans, which are part of a competitive strategy to gain a greater market share and expand its dominance of the industry. The aim is to increase annual production from 2.1 million ounces (in 2001) to 3.5 million ounces by 2006. Anglo Platinum's access to additional ore reserves ensures that the expansion plan will be sustained for years to come.

In a mature industry such as platinum mining, two competitive strategies are available: to expand operations to exploit reserves (to gain greater market share) and to improve recovery/refining operations (to reduce costs), or to extend increasingly into downstream activities. Anglo Platinum has chosen the former strategy, which, given the firm's historical reliance on R&D for competitive advantage, provides much of the motivation for pursuing the partnership. Concern with the inefficiency of a particular upstream operation (the refining operations are all viewed as efficient), has determined the nature of the project and strongly influenced the higher education partner chosen.

The reliance on R&D for competitive advantage accounts for much of the secrecy, which in turn, explains in part the limited nature of the partnership: there are only three partners (including Anglo Platinum) and the core research is undertaken by two employees of the sole industry partner.

The starch-based plastic compounds network

The research at the core of this network is concerned with finding a biodegradable plastic derived from corn starch, which has equivalent properties to petroleum-based plastic but is cheaper to produce. All aspects of this endeavour produce research challenges: to develop a corn starch polymer that is biodegradable; its need to have the properties of plastic; and, importantly, the ability to compete in price with petroleum-based plastic.

Petroleum-based plastics have a number of advantages: they are low-density, low-cost, easily processed, and possess design flexibility. However, they have two drawbacks. Firstly, they are produced from a non-renewable source. Secondly, they are not biodegradable and the resulting problem of solid-plastic waste constitutes a threat to the environment. These factors have made the search for a biodegradable polymer attractive in a number of countries, particularly in Europe and the United States. Starch, which is a cheap and plentiful natural polymer that occurs in plants such as potatoes, wheat, maize and rice, has become a key avenue in the search for a commercially viable biodegradable plastic. Two major challenges face this endeavour. Firstly, starch is not thermoplastic: heating it causes thermal degradation before it melts and flows. As a result it cannot be processed like a conventional plastic. Secondly, starch is hydrophilic and partly water-soluble: packaging made from starch disintegrates when placed in contact with water or in conditions of high humidity.

Research into starch-based plastics is well established in Europe and the United States, but it is not yet a widely used packaging material. Fully biodegradable synthetic polymers such as polylactic acids and polycaprolactone have been commercially available since 1990. However, biodegradability is slow and they are more expensive than conventional plastics. To some extent this has been overcome by blending starch with hydrophobic polymers, to increase its water resistance and biodegradability. New technologies are constantly improving starch's thermoplasticity and have allowed applications to be extended to injection moulding, extruding lamination and film forming. Extrusion can alter the structure of corn starch to make totally biodegradable packaging, while the modification of lactic acid can make other biodegradable plastics. These innovations, however, are relatively expensive and, to date, applications have been confined to niche markets in Europe and the United States (see www.csir.co.za for further details).

The network project aims to develop a biodegradable plastic without blending in synthetic polymers. The plastic must, furthermore, have melt-flow characteristics that allow it to be processed in conventional injection moulders. It must also be water resistant, which has necessitated research on additives to achieve this resistance. Importantly, the material must be relatively cheap. While research is advanced in Europe and the United States, in South Africa it is new – and somewhat different. In Europe the base starch is derived from potatoes rather than corn, which means that the chemical challenges are not the same. The local research network is also attempting a new approach to the problem. Knowledge of developments in Europe is important for the South African researchers, who want to avoid any duplication or missed opportunities. This is a factor behind links with European researchers (see further below).

Research into starch-based polymers falls into the well-established research field of polymer compounds. In terms of industrial sectors, however, the situation is more complex. The raw material (corn) is drawn from the agriculture sector and its processing (to produce corn starch) falls partly within agri-processing and partly within the food and beverage industry (as well as, to a lesser extent, in the pharmaceutical, textile, paper, adhesives, and spray-drying sectors). The main market for the corn starch polymer, should it be commercialised, will be the plastics and packaging sector. It will be an entirely new product in that market, as no other firm in the country is manufacturing corn starch plastics for commercial use.

The plastics market is, however, not the focus of the industry partner, and the nature of competition in this market does not appear to be of particular concern within this network. The corn starch production partner is African Products, the largest wet-miller of corn in Africa and an exporter of starch, glucose and related products. It processes a single raw material source – corn – into a very wide variety of products, including specialty and modified starches, glucose, maltose, dextrose syrups, dextrose monohydrate, glucose powder, caramel colouring, maize germ, and corn steep liquor. These products find application in a wide range of industries. Such diverse products and processes as animal feeds, baking, brewing, briquetting, building bricks, confectionery, corrugation, dairy products, frozen foods, beverages, jams and processed foods benefit from corn starch additives. The growth of the firm is determined by its expansion of the downstream applications of corn starch and its main concern is to expand the market for corn starch by expanding the range of its value-added applications. It is constantly sourcing its customers, the CSIR, and other bodies, to come up with new ideas and innovations that could add to the list of corn starch applications. Competition for market share through cost-cutting does not appear to be a major issue. Instead the firm's competitive strategy focuses on expanding the market through downstream applications. This is the primary reason for African Product's interest in R&D.

In line with this strategy, African Product's participation in the network is seen as a risk venture (and the outlay as risk capital). However, the development of a final product will not in itself be an adequate return on the investment. The real goal is to commercialise the product on a large scale. African Products calculates that it must produce up to 100 000 tons of the base compound a year to warrant setting up an injection-mould plant. Finding a large overseas market is therefore critical to commercialisation as the South African market is too small to reap economies of scale. The firm's experience of exporting will stand it in good stead in this regard. Clearly, if the project is successful, the returns are potentially enormous. The plastics and packaging market is extensive and the European market, where there are acute concerns over the environmental aspects of plastic packaging, would be particularly lucrative. Of course, the cheaper the product is the better for the expansion of the market and profitability. African Products is therefore particularly interested in the use of waste for generating corn-starch plastics – an aspect which has been an important feature of research in Europe.

The newness of the research in South Africa, the differences between the raw material in Europe and South Africa, and the limited commercialisation of existing starch-based plastics in the United States and Europe, partly explain the network's relative openness regarding the project. No competitors in the country are conducting similar research or are in a position to capitalise on the research. Furthermore, the quantities that need to be produced to make commercialisation viable tend to rule out easy entry into this market.

The beneficiation of phenolics network

The beneficiation of phenolics network has a wider scope, rooted in the nature of the process, which in part explains the greater number of partners involved and the more complex structure of this network.

Phenols are pure chemicals distilled from chemical raw materials which have a wide variety of applications. The research focuses on the process of upgrading phenols to a higher level to create a new product, which can be further upgraded, and so on. As the highly resource-intensive process of upgrading and beneficiation continues, the volume decreases, products become more differentiated, and the price increases. The fine chemical products that emerge downstream carry enormous potential. The network is also concerned to find cheaper, cleaner and quicker synthesis methods for the beneficiation processes. It is therefore concerned with both product and process innovation. However, no specific details could be obtained about the research because of confidentiality agreements.

The range of products in the fine chemicals market is open-ended (it includes, for instance, plastics, antiseptics, anti-oxidants, brake pads and insect repellents). This means that the network is not concerned with developing one particular application, but is involved in on-going research on process and product innovation across a range of applications, each of which could constitute a separate project. The applications are in turn spread across a variety of markets and can require a larger or smaller production capacity. This provides an explanation for the complexity and fluidity of the network: new partners, particularly new (smaller) industry partners, can be added according to the nature of the particular application being researched.

The architecture of the network is not simply a reflection of the process. It is also influenced by the structure of the South African chemical industry and the changes it is going through. The industry is an important part of the manufacturing sector and the economy. It contributes up to 25 per cent of the manufacturing GDP and six per cent of the total GDP. It is extremely diverse, spanning a wide range of sub-sectors from liquid fuels, to commodity inorganic chemicals, and to fine chemicals. The largest sub-sector is liquid fuels, followed by plastics conversion and pharmaceuticals; with the industrial chemicals sub-sector having shown strong growth over the last few years (AMTS 2003 Vol 2: 98–101). The chemical industry is dominated by commodity-producing firms, and very little has been done to develop the downstream, value-added part of the industry. This is an inherited structural bias that is rooted in the historical concern to make the country self-sufficient rather than globally competitive. This bias accounts for the decline of the industry over the last ten years in the face of increased exposure to competitive global markets. It also accounts for the current shift by some firms to focus more on downstream activities.

Despite the structural problems facing the chemical industry, it has certain advantages that position it well to adjust and grow. Amongst these are low energy costs, abundant coal, inorganic materials and natural products, some world-class technology, access to a unique set of relatively cheap chemical intermediates from firms such as Sasol, and several world-class higher education institutions. Sasol, in particular, is a major feature, having transformed itself into a global chemical company in the last decade. The growth of the South African chemical industry will depend on the performance of the global economy. The industry is highly sensitive to international markets, either for its inputs (for instance, the oil price) or its outputs – given that about 60 per cent of production is used in downstream manufacturing in the chemical sector (AMTS 2003 Vol 2: 96).

The downturn in the global economy is increasing pressures on the local industry to seek competitiveness through innovation and networking rather than through economies of scale and vertical integration, which increases the significance of partnership with higher education. Such interdependencies are not entirely new to the industry. Its great diversity and the nature of the pipeline led to the development of many linkages in the past. Now, the expertise situated at higher education institutions will be particularly important as the industry seeks to expand into downstream activities. Partnerships enable firms to access such expertise much more cheaply than setting up their own R&D facilities would do.

The phenolics network reflects these broader structural shifts in the industry as well as the competitive strategies that are emerging to cope with the increased pressure from global markets. The nature of the network also reflects many of the competitive advantages possessed by the industry. Sasol, the only coal-to-oil facility in the world and the producer of a range of unique raw materials, is an indirect partner via a joint venture with an American company called Merichem. Merisol, the joint venture, was established to enable Sasol to add value to its raw materials. The initiative is therefore part of Sasol's strategy to expand downstream into the chemical industry.

Merisol is seeking to expand the existing range of applications of phenols. This has led it to establish links with research centres at two higher education institutions: Port Elizabeth Technikon and the University of Cape Town. Common interests between one of the centres and the CSIR led to its inclusion. The research has resulted in the spin-off of parallel technologies that could be commercialised further downstream by smaller companies. At present this is being done via two channels. One is a tiny firm called GradChem Solutions. The other channel is the South African Chemical Technology Incubator, which promises a wider and more systematic route to the commercialisation of innovation by small firms. The nature of the phenolics network has been strongly influenced by changing market conditions and competitive strategies, particularly on the part of Sasol. At the same time, the range of applications has opened the way for small firms to benefit.

The influence of process, industry and markets

There are clear similarities between the three cases discussed here in terms of the industrial and market environments within which the industry partners operate. The role of large firms in the NMD field is reinforced – the primary industry partner in two cases is a very large firm dominant in the market, while in the other case it is a leading firm backed up by two large and dominant parent firms. All the industry partners have ready access to large reserves of raw material through established pipelines, although in the case of African Products, the supply of raw materials is subject to fluctuations, largely dependent on the weather. The industry partners are also, despite their dominant positions in the market, facing stiff competition, which is exerting strong pressure on the firms.

In the face of this competition, the strategy used in the recovery of metals case differed considerably from those used in the other two cases. It centred on expanding market share and cost effectiveness, leading to a focus on optimising upstream activities. The competitive strategy in the corn starch and phenolics cases was directed at expanding downstream applications, thereby growing the market for the product, with the processes focused on beneficiation of raw or intermediate material to produce new applications.

A related distinction is the 'gap' between the research and its commercial applications. In the case of Anglo Platinum, any improvements realised from the research would quickly impact on the recovery of metals process, and in turn on the firm's market performance and its bottom line. Commercialisation is a much less immediate prospect in the other two cases, however, since the research is some distance from a significant breakthrough. Commercialisation here will also require substantial new capital investment (in plant, equipment, and so on) as well as investment in marketing and related activities. At the same time, the fact that commercialisation is part of an established pipeline supplying raw or intermediate materials, restricts entry by competitors. This adds another dimension to the competitive situation of each firm with regard to research.

The focus, or absence of focus, on downstream applications, and the imminence or otherwise of commercialisation, have clearly impacted on the nature of the networks. In the case of the recovery of metals partnership, the narrow focus on a particular upstream activity has restricted the number and the nature of partners. To address the specific area of concern, the industry partner needs only expertise. There is no place for secondary industry partners and there is no need for involvement by an industry intermediary (although a university-based intermediary has facilitated the functioning of the partnership). Moreover, the immediate commercial value of the research has accentuated Anglo Platinum's concerns about secrecy. The focus on downstream applications provides greater opportunities for secondary industry partners to be involved in the other two cases. Spin-off innovations that the main industry partner does not have the capacity for, or interest in commercialising, can be put out to secondary partners. The prospect of commercialisation of a new product can also attract an industry intermediary partner such as the CSIR. Its brief to develop collaborative relationships and to bridge the gap between research and commercialisation gives it a keen interest in being involved in networks that have new processes or products as their goal. This distinction will become more apparent when the structure and dynamics of knowledge generation within these cases are analysed – as is done in the following section.

The structure and dynamics of knowledge generation

The focus now shifts to describe the networks themselves, by providing an overview of the partners at each node, their interests, and how these motivated the development of the network, and then outlining the network structure that results. The governance and functioning of the network, particularly regarding the ways in which knowledge is generated and communicated between partners, provides a further focus, and finally, the factors that constrain the development and achievements of the network are considered.

The partners and their primary motivation

The recovery of metals partnership

The sole industry partner, Anglo Platinum, introduced above, is a very large company, 68 per cent of which is owned by the Anglo American Corporation. Anglo Platinum is listed independently on the Johannesburg Stock Exchange as well as the London Stock Exchange, and is represented on the Brussels Bourse via International Depository Receipts. The Anglo Platinum group is comprised of a holding company and three wholly owned subsidiaries: Rustenburg Platinum Mines, Potgietersrust Platinums Limited, and Lebowa Platinum Mines Limited. It is the world's leading producer of platinum and in 2000 had record earnings of US$1 billion. It is a vertically integrated operation that mines, processes, refines and markets PGMs. Locally, it operates six mines, two smelters, a base metals refinery and a precious metals refinery. The company is also involved in a number of overseas ventures, notably exploration in Canada and evaluation of mineral properties in Russia's Ural Mountains. Total employment stands at well over 45 000.

Anglo Platinum sees itself as being at the cutting edge of mining technology and therefore places great importance on research. This is a key aspect of its competitive strategy. It has an in-house R&D facility, the Anglo Plats Research Centre, which employs approximately 200 people, most of whom are chemical engineers. The work is divided between five specialised groups. The Process Research Group (PRG) is the unit involved in the partnership. This group is concerned with the 'back-end' of recovery of PGMs, that is from the smelter stage forward, including the recovery process. The PRG unit has 14 members: 11 researchers and 2 technicians (plus one non-scientist), of whom 10 were chemists and 3 chemical engineers.[10] All are highly qualified (there are several PhDs and MScs, and the minimum qualification is a BSc). The PRG has two main areas of research: technical support for short-term plant optimisation and longer-term projects aimed at generating processes and products relating to process control. Technical support predominates but the PRG hopes to expand longer–term projects.

The partnership involves two higher education research centres, the Centre of Electro-Chemistry and the Centre of Material and Process Synthesis (COMPS), both at the University of the Witwatersrand. The Centre of Electro-Chemistry was established in 2000 by a senior academic in the School of Chemistry. At the time he was the only person with any expertise in electro-chemistry employed at the university, and the centre was envisaged as a way of using this expertise. The centre now has one electro-chemical engineer and 19 chemists, as well as 13 post-graduate students studying in the field, utilising 7 laboratories operating with state-of-the-art equipment.

The Centre of Material and Process Synthesis plays an important dual role, functioning as a university research partner, and as an intermediary partner. The centre was established in 1998 by two senior academics in the School of Chemical Engineering. Its initial focus was to interact with industry by using process synthesis techniques for chemical engineering problem-solving. Over time the academics developed this technique and applied it to the academia–industry research and consulting interface, across disciplines. In the process, COMPS has shifted from being simply a chemical engineering research centre to become, in effect, a university-based intermediary between academic researchers and industry.

It was, however, found necessary to bring in a group of consultants to take on project-related functions that the academic staff did not have time to perform. These consultants, all of whom are engineers, are responsible for activities such as sourcing relationships with industry, managing the contracting phase, overseeing technical aspects, managing the legal aspects of intellectual property rights and contracts, managing funding, proposals and reporting, and performing a quality assurance role. The consultants are multi-skilled, which contributes to the centre's highly flexible, creative and non-hierarchical mode of operating (it was described as being run along the lines of a 'church bazaar'). Its reputation has spread across the university, which has further facilitated its ability to put together multi-disciplinary teams.

The success of COMPS is reflected in its current portfolio of projects. It manages a total of 50 THRIP projects with 50 different industry clients on behalf of academics and units in a variety of disciplines, from chemistry to social science. Current THRIP project funding at the university amounted to R26 million in 2003. The staff complement is 2 directors, 2 academics, 6 consultants, 4 administrators, and 35 student researchers. Success, however, is posing a potential threat. COMPS performs an external interface function more typically located within a university's centralised management structure. This has generated discussion about the possibility of its becoming more centralised, which poses obvious dangers to the flexible and creative model that has evolved so far.

A number of factors contributed to the formation of this partnership. First, there was a strong interest on the part of the academic head of the Centre for Electro-Chemistry to

10 The reader is reminded that all figures apply to the time at which the survey was done.

promote the role of electro-chemistry in the search for renewable sources of energy. He argued that it is only through long-term partnerships with industry that the fundamental shift can take place from processes that rely on non-renewable sources of energy to processes that use alternative sources. Funding from industry is critical for the research that needs to be conducted, which would increase the level of expertise in the field and enhance the technological capacity of the university. These commitments led to him to approach Anglo Platinum about ten years ago, to demonstrate the potential uses and applications of electro-chemistry. Initially, Anglo Platinum did not show much interest, but some time later contact was re-established. It is likely that geographical proximity and the limited expertise in electro-chemistry in the country (and within its own research centre) were factors that led Anglo Platinum to establish this particular relationship.

Once initial discussions between Anglo Platinum and the Centre of Electro-Chemistry were under way, COMPS was brought in, precisely in its role as intermediary. The Centre required assistance in formalising and managing the relationship with Anglo Platinum. However, its scientific expertise in chemical engineering led to COMPS becoming involved in the partnership as a research partner as well. A written agreement was then fashioned to formalise the functioning of the partnership, which has been updated annually. A separate intellectual property rights agreement was being finalised at the time of this study. The COMPS research is funded entirely by Anglo Platinum, and as will become evident, this gives it a great deal of power in the partnership.

The starch-based plastics network

The primary industry partner in the starch-based plastics network is African Products, a division of the Tongaat-Hulett group, a very large corporation with its roots in the growing and refining of sugar. Tongaat-Hulett is in turn part of the Anglo American Corporation. African Products is a substantial and well-established company in its own right, with an annual turnover of approximately R1 500 million. It has five manufacturing plants located around the country and permanently employs about 750 people. The company has a research laboratory but this is dedicated to food technology research and employs only two researchers. It does not have the facilities nor does it have the expertise to do its own research in polymer compounds. One of its strategies is therefore to work with others to conceptualise and develop new products that hold cost or competitive advantages.

A secondary industry partner in this network is Xyris Technology. This was established in 1990 by the current director of the Institute of Applied Materials (IAM) at Pretoria University, the main higher education partner. He established the company prior to his university appointment, but remains a co-owner and is its research director. He therefore constitutes a very tangible point of overlap in the network. Xyris produces customised plastic additive compounds. The firm's aim is to provide local and international customers in the polymer-converting industry with competitive advantage, by supplying them with specialised masterbatch additive packages that are cost effective, environmentally friendly, and safe to use. Its products include flame retardants, corrosion inhibitors, barrier additives, and purging compounds.

Xyris is a small firm with an annual turnover of R3.5 million and a permanent staff of four to six people, though this is increased by contract labour when the need arises. Importantly, no research is conducted at Xyris; instead the firm sponsors students at IAM to pursue research on developing a starch-based plastic, which is a particular area of interest to the firm.

A consortium and another firm are on the fringes of this network, but at present neither qualifies as a fully-fledged industry partner. The consortium is the Magnesium Compound Consortium (MCC), which consists of two firms (a mining and a chemical company), two higher education institutions (Pretoria University and Pretoria Technikon), and one private individual. It was established to develop a compound for use in piping in the mining industry. Nine researchers are involved in the work of the consortium, which is funded by the National Research Foundation (NRF). The link with the starch-based plastics network is through hydrotalcite (an anionic clay), the compound that the MCC is developing. IAM are keen to utilise hydrotalcite in their starch polymer research.

The other firm involved on the network fringe is Boart Longyear Ceracast, a large company (also part of the Anglo American Corporation) supplying products, systems and services to the natural resource industry, the construction and quarrying industry, and other industries. The products include a vast range of high-precision components made from low-alloy steel, nickel-boron alloy, and stainless steel. Researchers at this company approached IAM with a view to using the waste materials from ceramic formulations. This interest does not directly relate to starch-based plastics but it involves polymer research and technologies.

The higher education partner, the Institute of Applied Materials (IAM), was established in 1996 with the appointment of the current director, as part of a broader initiative of the Department of Chemical Engineering at the University of Pretoria to build a strong research culture. IAM is at present the only full-fledged research institute in the department but there are a further ten research groups. It was established with a brief to conduct interdisciplinary materials research, with participation from a number of other departments, including Materials Science and Metallurgical Engineering. It has four research focus areas: polymer additives, biodegradable polymers from starch, functional inorganic systems and ceramics, and nuclear-grade carbon from coal. The Institute places great importance on collaboration and has developed relationships with a number of individuals and institutions.

Along with the director, who is a senior academic, IAM has six members of staff including support staff. Additional staff from the Department of Chemical Engineering are involved in projects on an ad hoc basis. The Institute receives industrial sponsorship and THRIP funding. There are 18 postgraduate students: 12 Masters and 6 PhDs, fairly evenly spread between the focus areas, and drawn mainly from African countries.

The CSIR, a significant intermediary partner, has been described in previous chapters. The Centre for Polymer Technology, the section directly involved in this network, falls within the CSIR's Manufacturing and Materials Technology business unit. This unit offers integrated solutions to complex manufacturing challenges through combining technology with business process optimisation and the necessary training and education. Within the unit, the Centre for Polymer Technology conducts projects ranging from bio-artificial liver-support systems to the production and beneficiation of indigenous fibre plants. A key project is the research on starch-based plastics. The involvement of the CSIR is possibly one of the reasons for the greater openness regarding the research being performed within this network.

The network is based on two well-established research relationships. The first, between the director of IAM and a scientist at the CSIR, developed during the 1980s when they worked together in the Centre for Polymer Technology. A second relationship has developed between African Products and the CSIR in the period since 1994, and resulted from the firm's strategy of identifying new applications for corn starch, and the need for additional expertise and research capacity. The fact that the CSIR had a Centre for Polymer Technologies and possessed considerable research expertise in the field of polymers made it a logical choice for African Products in pursuing corn starch plastics research. Importantly, it also has the facilities and equipment needed for advanced polymer technology research, as well as a strong interest in developing projects through to commercialisation. The project not only attracted the CSIR as a way of advancing research in polymers; it also fulfilled its mandate to collaborate with both public and private sectors in undertaking market-driven research and development that would benefit the country – particularly because the product would be environmentally friendly.

When African Products and the CSIR started the project on starch-based plastics, the CSIR scientist involved the head of IAM because she knew he was an expert in the field, in which they themselves lacked sufficient research capacity. In addition, he was known to be very energetic and trustworthy, as well as having experience in commercialisation. The mutual respect between these two individuals is a key aspect of the network. The network was seen as serving the purposes of IAM in that it fulfils its brief to engage in collaborative work and it provides postgraduate students with real research problems and good, relevant experience. However, IAM was not only interested in the challenging work for students, but also in the entrepreneurial possibilities and potential for commercialisation.

The University of Pretoria and the CSIR have a formal collaboration through the Southern Education and Research Alliance (SERA), and African Products and the CSIR have a history of collaboration, so the new network was facilitated without any problem. The CSIR is key for a number of reasons. First, the primary relationships in the network are between the CSIR and African Products, and between the CSIR and IAM, with only a weak relationship between African Products and IAM. The reason for this asymmetry is that African Products did not have a prior relationship with IAM and at the outset was somewhat suspicious of the ability of academics to meet deadlines. It prefers to work through the CSIR, with which it has developed a good relationship. Similarly, there is a strong personal relationship between key scientists at the CSIR and IAM. Second, the CSIR is seen by all to be the partner with the necessary skills and systems to manage projects and funding, and it is trusted to negotiate fair deals. IAM was too busy to take on this role, and the industry partner preferred to leave it to the CSIR. The CSIR therefore performs the role of a true intermediary in the network.

The network is funded by contributions from both industry partners. African Products has provided R300 000 and Xyris, the secondary industry partner, has put up R100 000. This amount has been matched by THRIP funding. Accessing THRIP funding consolidated the core of the network, because only IAM–University of Pretoria, the CSIR and African Products are parties to the THRIP agreement. The network has, however, continued to develop outside of the core relationships. Xyris Technology's involvement in the network was to some extent inevitable, given the interconnecting roles of the director of IAM, its own reliance on sponsorship of research at IAM, and its specific focus on manufacturing additive packages for the polymer-converting industry.

Further potential partners have been identified, mainly as a result of IAM's search for other industry partners to contribute to polymer research in general. The Magnesium Compound Consortium and Boart Longyear Ceracast both have very specific research interests. The head of IAM (both in this capacity and that of Xyris research director) is also responsible for developing links with the TNO, a science research council in the Netherlands, and other European research institutions and universities, themselves part of a strong network. There is considerable interest in strengthening the relationship with the European network, because Europe at present leads the way in starch-based plastics research and commercialisation.

All the core partners agreed that one of the key motivations for their participation in the network – other than a common interest in the technology – was the recognition that none of them could achieve much on their own. Each was therefore reliant on what the other partners contributed towards their common goal. IAM brings research expertise and research capacity (including students) to the network; the CSIR brings polymer expertise, facilities and equipment, and an interest in commercialisation; Xyris brings sponsorship, as well as expertise and manufacturing capacity in the area of additives; and African Products brings venture capital, the capacity to commercialise the project, and international connections. None of the partners are closed to the notion of further expansion of the network, but any such developments will be determined by the research objectives, and the ways in which future partners can contribute to the research. To consolidate new relationships and upgrade them to the status of fully fledged partners would require a contribution of funding as well.

The beneficiation of phenolics network

Merisol, the primary industry partner, is a joint venture of Sasol, the oil-from-coal giant, and Merichem, a large United States-based multi-national corporation, with 50:50 ownership between the two, and equal profit-sharing. The joint venture was initiated to provide Sasol with an avenue for adding value to the raw materials it produces – which it previously sold to Merichem in unprocessed form. The joint venture is a key part of Sasol's plans to diversify production and move downstream in the chemical industry. Merisol's annual turnover is substantial: about R350 million in South Africa and around $130 million globally.

Merisol's core business is adding value to phenols. It has the technology to distil and purify raw material into phenols, with a wide range of applications – for instance, it is the biggest producer of coal-tar products in the world. About 90 per cent of all Merisol's products are exported. The company believes that it must constantly improve its technologies and innovate, to increase its competitiveness in global markets. It has two production sites, one in Sasolburg and the other in Houston. The former employs about 80 people and the latter about 180. All the South African staff members are highly skilled; even the process operators have a minimum qualification of T3. The firm has a very flat management structure and a team-work approach. There are only three broad categories of employees: the leadership team, line management, and technical staff. Team leaders play a critical role in co-ordinating the activities of the firm.

Merisol has a relatively small R&D budget (only about 2.5 per cent of its budget is spent on new product development) and no R&D staff. This is partly because there is a low return on investment in new products since the success rate in terms of commercialisation is very low. It is also partly because the firm can draw on the R&D capacity within Sasol and Merichem. Like Anglo Platinum, Merisol engages in research to provide support for operations and to solve current problems, but it also undertakes longer-term research related to innovation, and oriented to downstream applications. Sasol's R&D is not, however, particularly useful to Merisol as it is not geared for this type of research. This factor, together with the firm's need to cut costs, minimise risks and avoid duplication, led to Merisol turning to higher education institutions for research input. The networks that Merisol has formed have reduced the costs associated with R&D and allow the firm to conduct applied research without the need to have in-house R&D.

Merisol has not attempted to commercialise all the processes and new products developed by its higher education partners. Because of its strategic priorities and a shortage of resources, it can focus only on larger commodity-based projects. Hence Merisol has encouraged its higher education partners to pursue the commercialisation of smaller projects and innovations with other industry partners. Gradchem Solutions is the most promising of these. The company was established in 1999 by two engineers (previously from Sasol R&D) to develop a reactor by utilising the technology and optimising the processes designed by the higher education partners. The firm is still in the early stages of commercialisation – it is tiny, with only two permanent staff members. It relies on the higher education institutions for the bulk of its R&D work, it outsources most of its production functions, and it draws on the South African Chemical Technology Incubator for marketing skills and facilities. It nevertheless plays an integral part in the broader effort to beneficiate phenolics, and the applied knowledge generated by its activities feeds back into the network via the higher education institutions.

The Port Elizabeth Technikon Catalysis Research Unit (PETCRU), a unit located in the Chemistry Department at the then Port Elizabeth Technikon, is the primary higher education partner in this network. It has three core functions: teaching, long-term research and staff development, and applied research and commercialisation. The head of the unit is a senior academic and a highly rated scientist. In total, PETCRU has 7 full-time staff members paid by the technikon, as well as 23 researchers and technicians employed by the unit on fixed-term contracts, and 33 Masters and PhD students.

The secondary higher education partner is the Catalysis Research Unit (CRU) in the Department of Chemical Engineering at the University of Cape Town. This unit was established in 1990 to consolidate and expand existing relationships with the chemical industry (see Cele 2005). The work of the unit is entirely dependent on the funds it receives, and it focuses exclusively on the needs of its industry partners. The CRU is headed by a senior academic, whose research involves the development of catalysts to start chemical reactions. The CRU employs five researchers in contract posts as well as a technician and an administrator. In addition, it draws on the skills and resources of six researchers at the University of Stellenbosch and has 25 post graduate students working on projects linked to the unit's contract research. The relationship between PETCRU and the CRU has been cemented by a strong commitment on the part of the heads of both units to applied research with commercialisation potential, and by distinct, complementary sets of expertise, skills and equipment.

There are two industry intermediaries in this network. The Food, Biological and Chemical Technologies (Bio/Chemtek) business unit of the CSIR aims at providing technology solutions in its three research domains – food, biological and chemical technologies. It has developed multi-disciplinary competence as a result of the interaction and convergence of these sciences. It undertakes work in all phases of the value chain, from early discovery, through concept formulation, to process selection, development and product formulation, and to customised synthesis and formulation. Bio/Chemtek has a large professional staff (100 have postgraduate degrees) consisting of scientists, engineers and technicians spread across the three main research areas. Importantly, the unit has facilities and equipment that are not available to most higher education institutions. For example, it has a pilot manufacturing facility, which gives it the capacity to expand the application of experiments to a scale not possible in a university or technikon. This means that Bio/Chemtek can play a multiple role in networks: research entity, sectoral intermediary, and commercial enterprise.

The South African Chemical Technology Incubator (Chemin)'s mission statement places it at the forefront of efforts within the chemical industry to shift to downstream activities. It was established first as the Chemistry Technology Centre at the Port Elizabeth (PE) Technikon, with funding from the NRF. The funding enabled the centre to purchase a large-scale synthetic reactor (the SIMULAR reaction calorimeter). A visiting European Union delegation recommended that the centre should become an incubator for the chemistry industry. A successful application for funding was made to the Department of Arts, Culture, Science and Technology. As a result, in 2002 the Chemistry Technology Centre was transformed into a Godisa[11] technology incubator, specialising in supporting the start-up and growth of SMMEs in chemical production technologies and products. Ownership shifted from the PE Technikon to a consortium of seven interested parties, with Merisol, PETCRU and the CRU all represented on its board.

Chemin's head office is in Port Elizabeth but it operates nationally and has links with universities, technikons, science councils and industrial laboratories through a network of centres. Some of its projects will be located in Port Elizabeth, with the others situated in other higher education institutions and firms around the country. The incubation process is geared to enhancing the profitability and growth of selected SMMEs, reducing the failure rate amongst such small firms, and improving their access to and use of technologies, through technical and managerial support. Chemin's strategy focuses on four areas: sourcing appropriate infrastructure and facilities required by incubator clients; providing a comprehensive range of technology incubation services; offering a range of business incubation services; and on-going assistance to develop collaborative linkages with other persons and institutions who are able and willing to contribute to the venture. Chemin's approach is that incubation is a process, which means that input can be provided anywhere along the 'pipeline', from prototyping, through pilot plant, to full-scale commercialisation.

Like the CSIR, Chemin has a number of roles in this network. Most of the members of the network are also on Chemin's board, so it provides an additional forum for interaction. It also to some extent fills the role of intermediary, together with the CSIR. Finally, it provides a pool of potential industry partners who can develop and commercialise some of the smaller spin-offs from the beneficiation technologies developed by the network.

Merisol's mission statement commits the firm to deriving 50 per cent of its income from new business every five years, which translates into a strong commitment to R&D. The network therefore developed from a long-established policy at Merisol of organising networks with higher education institutions. The choice of a specific partner is dictated by what an institution has to offer. The expertise and experience that had developed at PETCRU made it an obvious choice for Merisol in this case. While the link between Merisol and PETCRU is strong, Merisol's purposive approach to partnering means that its relationship with Bio/Chemtek and the smaller firms is much looser, because it has its

11 The Godisa Programme – led by the Department of Science and Technology and supported by the Department of Trade and Industry and the European Union – provides technology support to South African enterprises.

own production processes as well as access to the technologies operated by Sasol and Merichem. There is, quite simply, little that it can gain from Bio/Chemtek.

PETCRU also has a long history of alliances with industry, driven mainly by the belief that applied research is of paramount importance, and by the financial constraints on research experienced at technikons. PETCRU has a strong interest in commercialisation and its starting point is to answer basic questions regarding the prospects of a particular chemical before there is any commitment of time and resources to research. Once a decision to proceed has been made, the basis for a network is laid, with role allocation determined by the expertise and capacity needed. The need for catalysis expertise and related equipment led to the inclusion of the Catalysis Research Unit at UCT, which already had a long history of engagement with Sasol. This in turn, through an established relationship, brought in the researchers at Stellenbosch University.

Bio/Chemtek became aware through informal contacts that PETCRU was working in the same area as the CSIR. Both institutions also had an interest in developing small firms in the downstream chemical sector and sponsoring students to do the relevant research. It therefore made sense to combine efforts and technologies. Good relations consequently developed over time between the staff at PETCRU and the CSIR. Bio/Chemtek brought with it infrastructure – such as the pilot manufacturing facility – which is not available at Port Elizabeth Technikon.

Chemin's inclusion came via its association with PETCRU. Given that Merisol was not interested in pursuing commercialisation of some of the smaller spin-offs of the network, it was logical that Chemin and small firms such as Gradchem would provide the path for developing these projects. For its part, Chemin gains much from the network. In order to provide the range of services and training required by its clients, Chemin is critically dependent on links with the technikons and universities and the CSIR.

The funding arrangements are complex (and largely confidential), as might be expected given the number of partners and overlapping linkages. More than half the funding that currently sustains the projects within the network comes from Merisol. This is channelled primarily to PETCRU, and from there some goes to the CRU. In addition, there is funding from THRIP and the Department of Trade and Industry, some of which appears to overlap with the funding Chemin receives via the Godisa Programme.

The consolidation of this network rests on a recognition by all the partners that the complexities involved in the process of beneficiating phenolics means that no single organisation possesses all the necessary expertise and resources. The technical, financial, marketing and other requirements of the beneficiation process compel the parties to collaborate. But the network has developed on the basis of specialisation ('only doing what you are good at') and avoiding duplication. This has created a dynamic, multi-disciplinary innovation endeavour. The role of a 'champion', up until now performed by the head of PETCRU, is vital in holding all together, driving it forward, and ensuring that there is continuous information flow.

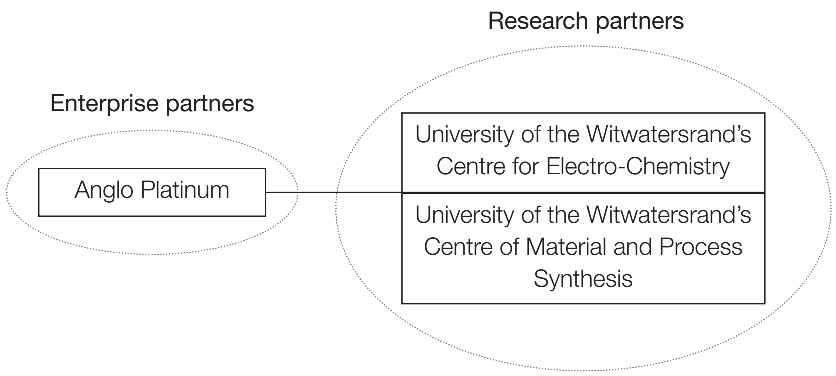
Structure and functioning

The core interests of each of the primary and secondary partners at the three nodes have been described, which informs understanding of the sequence of events that led to the establishment of the network. It is evident that each partner has a specific motivation for initiating the relationships. This section will outline the structures that result, and describe the patterns of collaboration and power dynamics within each network, as it goes about achieving its goals.

The recovery of metals partnership

The recovery of metals partnership is simple and the links are limited to a dyadic relationship between industry and the university partners. The structure of the partnership is displayed graphically in Figure 4.1. In fact, the functioning of the partnership centres on two researchers in the PRG at Anglo Platinum who have been enrolled for full-time master's degrees at the University of the Witwatersrand. One, a chemist, is supervised by the head of the Centre for Electro-Chemistry. The other, a chemical engineer, is supervised by one of the directors of COMPS. There is a great deal of interaction between the two supervisors, so they effectively act in a joint capacity.

Figure 4.1 The recovery of metals partnership



The post-graduate research conducted by the two student-employees, together with the inputs of their supervisors, thus constitutes the knowledge generated by the partnership. The electro-chemistry student spends one day a week at the Centre for Electro-Chemistry and the other days at the Anglo Platinum Research Centre. The chemical engineering student is based full-time in a COMPS laboratory. The interaction between these student-employees and their supervisors is the primary interface of the partnership, with an academic dimension, namely the completion of the master's degrees. There exists simultaneously, and more importantly, an applied dimension, to which the students and supervisors are contributing.

The university partners provide expertise in the form of supervision, as well as the necessary facilities, such as laboratories and equipment. They attend to the day-to-day direction and decision-making regarding the research, and deal with any technical problems that might arise. In addition, COMPS manages the relationship and sees to contractual and other formal aspects of the partnership. Besides providing two researchers and funds to pay the salaries and fees of the two student-employees and to procure the necessary additional equipment and research-related expenses, Anglo Platinum plays a strategic role: it defines the goals of the research process and ensures that it stays on track.

The roles of each partner are straightforward and traditional. Hence it is not surprising that each has a good understanding of their role and that there has been little or no friction. The initial agreement fashioned by the partners, which provides a framework to regulate the research interaction and the contributions of each, is a purely formal expression and appears in practice to have little bearing on the partnership's functioning.

Knowledge transfer takes place through the primary interface of the supervisory interaction. At this level the knowledge-generating and communication process is close-knit, involving both intensive formal and informal interaction. Outside of this interface, knowledge transfer is much more formal and less intensive. This takes place via quarterly meetings between the partners at which the student-employees make a presentation and provide the PRG with a progress report. These meetings were originally intended to be monthly but in practice have taken place about every three months. In the longer-term, however, the knowledge transfer between the university partners and Anglo Platinum will be more explicit. Once the student-employees complete their studies they will return to the PRG bearing with them the knowledge they have gained, which can then be applied in a variety of ways and on a day-to-day basis.

Knowledge has also been distributed more broadly via presentations at other forums, but this has been limited by the restrictions that Anglo Platinum has placed on publication and dissemination of the research. Only those aspects of the research that do not 'directly' compromise confidentiality may be made public, so the student-employees may not mention in their theses – or elsewhere – any findings that could reveal the details of the research process or its results. The same restrictions apply to the supervisors. At the time of the study, there was no written agreement regarding confidentiality, although such an agreement had been prepared and was due to be finalised. COMPS has played a key role in the preparation of the agreement dealing with confidentiality and intellectual property rights, as part of the services it provides. Such agreements usually involve a delicate balancing act: they must protect the rights of academics but without driving industry partners away. In principle, the university is not opposed to secrecy agreements, as outlined on the COMPS website (www.comps.wits.co.za):

> Secrecy agreements are entered into between the client and the University of the Witwatersrand, Johannesburg. In general, the process specific information is regarded as the property of the client, and information pertaining to problem solving techniques as that of the University.

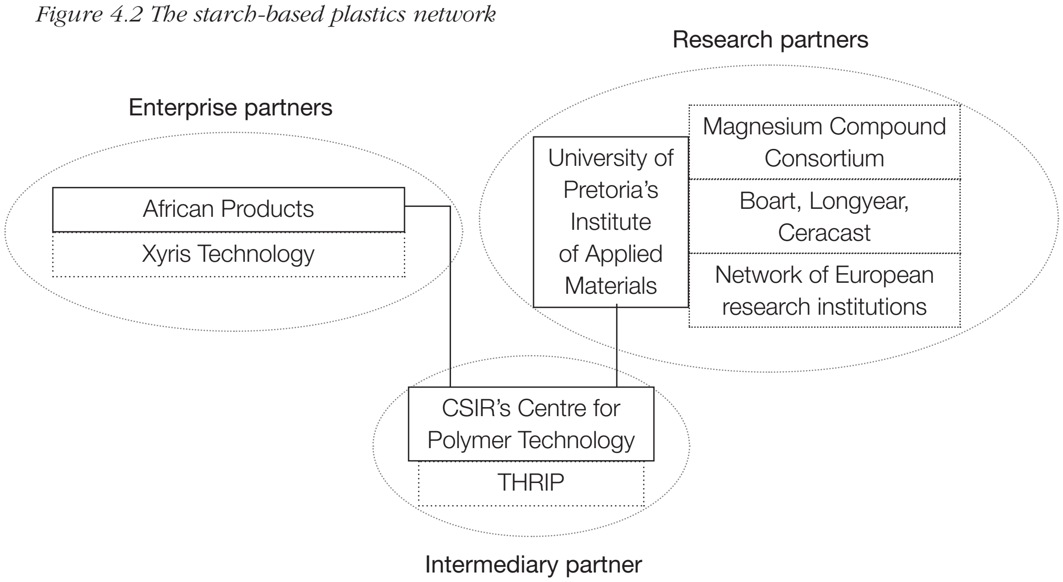
However, the partners view the agreement as a formality and believe that the mutual trust that has stood them in good stead so far will continue to be the primary mode of governance. While trust does play a role, the main factor is the power that Anglo Platinum wields in the partnership. The fact that it is the sole funder and the primary researchers are its employees must be a strong incentive for those involved to comply with the restrictions on publication.

While the concern over secrecy does not appear to have given rise to tension within the partnership, it has almost certainly restricted its potential. In fact, it became evident that this partnership does not display the typical features of a technology co-operation network. It is in essence a contract form of partnership (Kruss 2005). In such a partnership, the motivation for higher education is strongly driven by the desire to find new ways to maintain traditional academic activities, to fund research programmes, centres or units, and thus to attract postgraduate students. For industry, there is a strategic research interest, usually aimed at addressing a specific immediate problem or at solving potential problems. Industry's needs are typically finite and short term, but may lead to more medium term and less finite relationships. There may be a degree of collaboration, in terms of identifying research problems, defining deliverables and reporting criteria, both during and after the project. This form of partnership may raise problems for the researcher, through the restrictions placed on intellectual property. There are varying degrees of mutual benefit evident in contract forms of partnership, but there is not necessarily an intellectual collaboration on the research itself, nor do such partnerships lead easily to significant innovation. The recovery of metals case clearly displays all the typical features of such a partnership, and contrasts strongly with the other ten cases in the study.

The starch-based plastics network

The starch-based plastics network is complex, as is evident in the structure displayed graphically in Figure 4.2, and is in the process of expanding. The asymmetry in the links between the core partners should be noted: there is a strong relationship between the CSIR and the two industry partners (Xyris and African Products), but a weak relationship between the industry partners themselves. Commercialisation would lead to a formal arrangement between the two in which Xyris would become the additives supplier. Outside of the core network there are peripheral associations with two more industry partners, as well as links with a knowledge-intensive network in Europe.

Figure 4.2 The starch-based plastics network



The research work of the network is conducted by IAM and the CSIR, mainly by master's and doctoral students under the supervision of local staff, who guide the direction of the research – with African Products involved in the setting of targets. The research is conducted in laboratories at the premises of both IAM and the CSIR, with the latter housing key equipment.

There have been a few constraints on the development and research work, particularly related to the capacity to complete the research. The most important constraint was the loss of key personnel, namely a project leader at IAM and one at the CSIR, both of whom moved overseas. A potential constraint is that most of the students are non-South Africans – a concern because they come from different education systems and language groups, and are unfamiliar with the research environment in South Africa. It was feared that they might not be able to move at the same pace as South African students, but at the time of the research it was not clear whether this would actually be the case.

This network is formally governed by the requirements of the THRIP agreement. The partners maintain strict adherence to these requirements because it is convenient, as well as being to the benefit of all parties concerned. The parties themselves were not involved in the negotiation of the THRIP agreement, leaving this to their lawyers – and believing that their time would be much better spent getting on with their research.

The geographical distance between the partners makes it difficult for them all to meet together on a regular basis. The IAM is (scattered over several buildings) at the University of Pretoria, with the CSIR only fifteen minutes away, but Xyris is located outside Pretoria, as are the partners in Midrand and Johannesburg, with Boart Longyear Ceracast further away in Postmasberg. The lack of daily face-to-face contact somewhat limits exchange and discussions – felt in particular by African Products and MCC. It was even more problematic for staff at Boart Longyear Ceracast, who could not always come to Pretoria for meetings. The network nevertheless had ways of keeping in contact, and reportedly the members all 'somehow always know what is going on'.

There is significant and regular formal exchange of information between the core members as well as with those parties on the periphery. Three levels of meetings are held. First, in terms of the THRIP agreement and reporting structure, the organisation of work and progress is monitored at formal quarterly meetings between the CSIR, the students and staff of the IAM, and African Products. Any major decisions about the direction of research are taken by consensus. There is reportedly no pecking order at these meetings: the partners are concerned with achieving their research objectives and not with who has the final word in any decision-making. Secondly, ad hoc meetings are held at the CSIR on a frequent basis to discuss work and direction. Third, formal meetings with the MCC and Ceracast are held at least twice a year to monitor progress in their research areas. Xyris Technology is kept constantly in touch with research progress. In addition, there is continuous informal interaction between staff, students and project leaders. The partners make a point of keeping in touch with progress, either by telephone or by email, and by occasionally visiting each other.

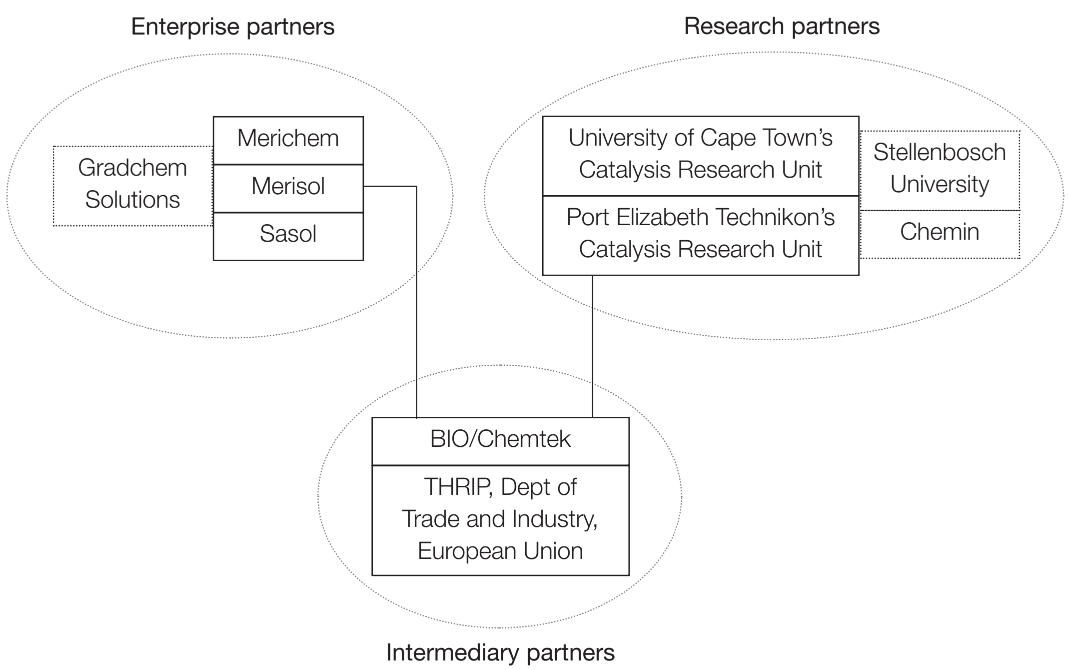
The most critical factor for governance in this network is believed to be the high level of mutual respect and trust amongst the IAM and CSIR researchers, rather than any formal agreement. The network is marked by having no hierarchy, by being very flexible and creative, and by being strongly goal-oriented. The industry partner maintains a hands-off approach, facilitated by the CSIR in its role as intermediary. Underpinning the mutual respect and trust is a working arrangement that the partners share the work and its results on an equal basis. There is a good understanding by each partner of their role and place in the division of labour. The intention of the arrangement is to cut out any unnecessary competitiveness over how much time and effort each researcher is putting in. The director of IAM sets the example: he was reported as having great passion for the research as well as enormous energy, and to be very generous with his time, expertise and ideas. Thus there have to date been no tensions between partners, other than that produced by the pressure to achieve the research objectives. So, while it is clear that agreements assist with regard to governance, trust remains the essential ingredient in the mix. There have been no tensions around intellectual property rights, mainly because the partners do not think an agreement is necessary until there is a product.

The beneficiation of phenolics network

Although the beneficiation of phenolics network began in an informal, ad hoc manner, it has become more structured over time, and new partners could be added in future.

The current structure is illustrated graphically in Figure 4.3. The primary industry partner (Merisol) does not have a direct link with the much smaller secondary industry partner (Gradchem Solutions), nor does it have strong links with Chemin or the CSIR, although these both perform a number of functions, and play a limited intermediary role. PETCRU and the CRU are at the heart of the knowledge-generating component of the network, with Stellenbosch University much more loosely involved via the CRU. Staff of these research units and their postgraduate students do most of the actual research work. The units have a very strong interest in commercialisation, which explains the relationship with Chemin and Gradchem Solutions, both of which provide avenues for the commercialisation of the technologies – which does not interest Merisol. Merisol has played a pivotal role in defining the strategic direction of the network, and an important part in managing relations between the partners. It was not, however, viewed as a dominant partner. In fact it was described as an 'ideal' partner: forward-looking, committed to innovation, and open to all kinds of suggestions.

Figure 4.3 The beneficiation of phenolics network



The role played by Bio/Chemtek in the network is varied and includes the employment of graduates, translating pure research into applied research, and offering limited manufacturing for commercialisation. It can therefore play an important role in reducing the gap between pure research and commercialisation. Chemin outsources several of its functions to the CSIR. These include the use of laboratories, the development of business plans, assistance in the commercialisation process, and facilitating the development of links between emerging and established businesses. Bio/Chemtek therefore represents a confluence of functions from all three nodes in the network: research institution, commercial enterprise, and sectoral intermediary. The multi-nodal role of the CSIR was, however, criticised by some, who argued that there was a conflict of interest in the CSIR's involvement in commercialisation to generate its own income, and that this was detracting from its research contribution to the network. It was suggested that commercialisation should be left to the industry partners.

Chemin also plays a somewhat diverse role: to some extent an intermediary between the higher education institutions and small firms, to some extent a provider of services to firms (for instance, Gradchem relies on Chemin for marketing skills and facilities), and to some extent an active agent in the commercialisation of the smaller beneficiation spin-offs developed by the network.

The contributions of partners can vary, depending on the stage in the innovation process. For example, in the early stages, research at the higher education institutions plays a crucial role, while the expertise in the CSIR and industry partners plays a more prominent role in the intermediate and final stages. However, the flow of knowledge in the network takes place in an iterative process, in which knowledge from a technikon or university is utilised by the other partners, yielding new insights that feed back into academic research.

There are no restrictions on the sharing of information between the partners. Critical factors underlying the free flow of information are the sound relations between the partners, and mutual understanding of their respective roles. This has been vital for the level of co-operation that has been achieved. Also important is the realisation by each partner that it has more to gain by sharing knowledge with the network than it has by working on its own.

The network is formally governed by a steering committee. Although it meets only twice a year, this committee plays a central role in directing the activities of the partners and in developing common objectives and plans for the future. It also has the responsibility of resolving any disputes that may arise – though at the time of writing none had arisen. The network is also governed by a range of confidentiality (regarding external dissemination of information) and other agreements. As developments within defined projects raise commercial possibilities, the parties generally seek to place their relationships on a more formal and clearly-defined footing. Such a project would therefore typically produce one or more agreements. Furthermore, a memorandum of understanding – to regulate the division of labour and resources, the protection of intellectual property rights, and so on – is also drawn up whenever this is deemed necessary.

However, the network evolved primarily through personal relationships between a few individuals and the partners have attempted to keep formal arrangements to a minimum. The day-to-day and month-to-month work of the network is largely governed by informal interactions that are driven by the research agenda. The network has developed organically and in an open-ended fashion, without rigid constraints imposed by any one partner. A mix of strong personal relations and trust with formal agreements has kept the network free of conflict. An additional factor is that none of the partners are in direct competition with one another.

A number of constraints or tensions were however identified, relating primarily to the structural limitations and imperatives of the higher education partners. For Merisol, the higher education partners were more difficult to control than an in-house R&D unit subject to the company's management structure would have been. Although annual work programmes are negotiated, the company has no guarantee of any results. It therefore chose close monitoring of the research, to ensure that the work remains on track. There was acknowledgement that higher education institutions are not well set up for engagement with industry. For instance, academics indicated that they receive very little assistance from their institutions in the drafting of contracts, the development of business plans, the use of accounting procedures, and so on. They have had to rely on personal contacts with lawyers, accountants, and banks to acquire the necessary information or services. However, Port Elizabeth Technikon has recently established an Enterprise Development Division to assist staff members with the financial, contractual and other duties that stem from networks with industry. This body is still at an embryonic stage and is under-resourced, but its creation signals a greater awareness on the part of the technikon regarding the facilities required for establishing structured networks with industry.

Comparing structure and dynamics

The main common feature of the three cases discussed here was the large size of the industry partners. A number of differences were identified between the recovery of metals case and the other two, relating mainly to a focus on upstream or downstream processes, the 'gap' between innovation and commercialisation, and the competitive strategies of the industry partners. Examination of the structure and dynamics highlights the distinction already observed. Indeed, it has been suggested that the recovery of metals partnership is in essence a contract partnership, and not a network. Exploring these differences is useful for identifying the determinants of the shape and functioning of networks.

The first difference is with regard to the approach of industry partners to R&D. While they all view R&D as vital to their competitive strategies, only Anglo Platinum has significant in-house R&D capacity and a strong R&D culture. The other industry partners have little or no internal R&D capacity. Whether as a result of infrastructural inadequacies, or initiated as a conscious policy, partnerships with other research institutions have become a business policy that is actively promoted. Anglo Platinum, on the other hand, appears to enter partnerships only when there are specific gaps in their own R&D expertise. This explains the narrow focus of their engagement with higher education institutions, as opposed to the much broader and open-ended engagement in the other cases, in the search for new technologies and fundamental knowledge. The ways in which R&D is structured, as well as the R&D policies of the industry partners, has therefore been a fundamental influence on the shape and focus of the partnerships.

There are more similarities than differences between the higher education partners. First, all the research units are centres of expertise headed by senior academics with established reputations. These academics are critical to the establishment and functioning of the networks, and tend to act as their champions. Second, their engagement with industry is part of an explicit policy on the part of a unit or academic department, as well, in some instances, as a university or technikon. This explicit policy is backed by a strong commitment on the part of the academics concerned to conduct applied research. Third, the ability of research units to facilitate and optimise such engagement is a problem experienced to varying degrees across the three cases. The way in which COMPS operates and its performance to date places it at the cutting edge in this regard, although universities like Pretoria University have dedicated centralised research management structures for playing such an interface role. The Port Elizabeth Technikon has recently set up a similar unit, but it remains embryonic, creating a potential tension and constraint in the network.

This may be one reason the intermediary partners are central to the two network cases. What stands out is the range of roles played by an intermediary partner such as the CSIR.

While it is primarily an intermediary between the industry and higher education partners, it also performs the roles of research unit and commercial enterprise. The presence or absence of intermediary partners also corresponds with the funding arrangements. The absence of an intermediary in the recovery of metals partnership corresponds to the fact that Anglo Platinum is the sole funder. The presence of industry intermediaries in the other networks is associated with more diverse funding sources. The primary source and allocation of funding thus has an impact on the boundaries of networks as well as on the power relations between partners.

There are distinct differences in the motivations for establishing networks. The need for complementary expertise and research capacity in order to achieve common objectives provides the foundation for all three cases. In the case of the recovery of metals contract partnership, the need is narrowly focused from the perspective of the industry partner. The other two cases require varied expertise, and hence the networks are larger, more complex and more dynamic, with partners being added over time. The process of identifying the appropriate partners also differs, with the two networks built largely on existing and well-established relationships, while the contract partnership was the result of a formal approach by a university. However, at this point all three are consequences of the activities of an individual academic. The initiative these academics displayed in making contact with industry and doing the extra work to establish research units was a critical factor in creating the conditions for sustainable networks.

Possession of complementary facilities and equipment are crucial for the inclusion of intermediary partners, again, not imperative in the contract partnership – given Anglo Platinum's extensive research facilities. The CSIR's administrative and management capability is also an important factor in mediating between industry and higher education, a function fulfilled largely by COMPS in the contract partnership. It is, however, notable that the businesslike approach of COMPS was viewed negatively by Anglo Platinum, which had not encountered such rigorous negotiation of financial and other interests in its previous engagements with higher education institutions. The ability to bridge the gap between research and commercialisation also accounts for the inclusion of intermediary and secondary industry partners in the two networks.

Postgraduate students and their supervision is vital for the functioning of all three cases, but represents the sole focus and form of research in the contract partnership. In the two networks, both of which have research units that attract large numbers of postgraduate students, the cost-effectiveness of research conducted by students is a major attraction to firms. However, student research is not their main focus, nor indeed their only form of research.

The functioning of all three cases has been without friction, which is somewhat surprising. Despite the common ground that exists between industry partners and higher education partners, there are a number of areas that could easily give rise to disagreement or dissatisfaction. Nor does the spatial dimension appear to be particularly important. While proximity does in part explain the links between some partners, it is apparent that geographic distance is not a critical factor and can be overcome without too much difficulty. One reason for this is that the roles of the partners in all three cases are well understood, either because of the simplicity of a dyadic structure, or because of a concern to maintain a clear division of labour between partners and to avoid duplication of roles and expertise. Second, and most important, the networks are characterised by trust and mutual respect. Agreements are used to regulate the division of labour and intellectual property rights, but these are generally seen as formalities that do not affect the way in which the partners function. In all three cases, knowledge is communicated in various ways and at different levels, from formal presentations and progress reports to informal interactions between students and supervisors, and from face-to-face contacts to emails and the telephone.

The building of the networks on a foundation of well-established relationships of trust is a critical factor, but there is not the same high level in the contract partnership. The powerful position of the industry partner in governing the relationship, although largely implicit, distinguishes it from the other two. The industry partner provided all the funds, which clearly gives it a powerful edge, and has imposed significant restrictions on the flow of knowledge, which considerably undermine the knowledge intensity of the relationship. This partnership functions in such a way that the lion's share of the benefits flows to the industry node.

One explanation for the unexpected absence of tensions in the networks is the distance between research and commercialisation. The nearer a research project gets to commercialisation, the greater the importance of intellectual property rights and contracts, and the greater the potential for the differing interests of partners to clash. The fact that commercialisation is still some way off in the starch-based plastic network has meant that none of the partners has shown much concern about intellectual property rights. The more complex phenolics network has dealt with these issues through a steering committee and a number of agreements, without any tensions arising – perhaps because only one smaller spin-off has approached commercialisation.

Benefits and future prospects

A finite contract?

The contract partnership does not yet appear to have realised its main objective: the development of a fundamental approach to understanding the recovery of platinum group metals. However, the research process has produced outcomes exceeding the original expectations, and some prototypes have been constructed. Achieving the main objective therefore remains a strong possibility. It is also apparent that the partnership is generating new knowledge, but the secrecy surrounding the research precludes a detailed exploration. It is almost certain that the industry partner will gain in terms of enhanced expertise. Both student-employees will return to the company with greater knowledge and skill, none of which will have cost the company a significant amount.

Other benefits have flowed from the partnership. It has enabled the Centre for Electro-Chemistry to extend its laboratories and obtain the use of state-of-the-art equipment, some of which it will retain on completion of the project. The Centre and COMPS both acquired postgraduate students to conduct important research that will enhance their reputations. The involvement of COMPS has released the two supervisors from management and administrative functions to concentrate on the research process. Their collaboration across the disciplines of electro-chemistry and chemical engineering has developed less tangible synergies and benefits. For COMPS, it also means another client, giving it ten per cent of the total project funding for the services it provides.

The power that Anglo Platinum has in the recovery of metals partnership, as well as the restrictions on knowledge dissemination, could threaten the future of the partnership. However, there are other factors that appear to be more significant. Economic considerations are primary: the strengthened rand has impacted on Anglo Platinum's profits and it was anticipated that this would result in a cut in the research budget. This threatens to delay the planned expansion of the partnership, which envisaged more student-employees being placed in the university research units. The expansion plan nevertheless pointed to a continuation of the partnership.

On the other hand, once the current student-employees have completed their master's degrees, it is planned that they will return to the Anglo Platinum Research Centre's laboratories, where they will continue with the research project. Some specialised equipment purchased for the project will also move to Anglo Platinum. This suggests the ending of the partnership, at least in its present form. The supervisors are concerned about the ability of the student-employees to continue their research unsupervised and would prefer that they continue with the arrangement by extending their studies to doctoral level. It is unclear whether the industry partner will agree to this proposal. The future of the partnership is therefore in doubt at this point. This is in keeping with its finite nature as a contract partnership focused on the immediate knowledge needs of industry.

Prototypes and commercialisation potential

To date, prototype seedling trays and other small items have been produced at the CSIR using a starch-based plastic compound developed by the network researchers. However, tests are still being run on the biodegradable and compostible qualities of the new compound, and it is not yet ready for commercial-scale production. Nor can the compound compete in cost with petroleum-based plastic. Further research to bring down the price and use the compound for other purposes, such as pot-plant holders, golf tees and food containers, is being conducted. In addition, Mondi, the large timber and paper company described in Chapter 2, has made a commitment to purchase seedling trays, and a food store chain is interested in replacing the polystyrene currently used for packaging with a biodegradable product (even if it has to pay a premium for an environmentally-friendly product). So, while African Products has not yet realised commercial benefits, the network has considerable potential, both commercially and in terms of broader national economic and environmental priorities – particularly important for some of the researchers.

A less tangible benefit has been the advance in knowledge in polymer compound technology. An important aspect of the knowledge generation, mainly from the academic perspective, has been that postgraduate students have been involved and benefited, while their research has resulted in publications. The network also meets IAM's brief to enter collaborative relationships with industry, and has played an important political role within the university, in that it demonstrates that such arrangements do not necessarily mean losing independence or compromising results. The benefits for the CSIR are that research in polymer compound technologies is being advanced and their laboratory equipment is being put to good use, which generates income. The cost to the CSIR is low: it is estimated that the cost of employing one professional researcher is equal to the total cost of four or five of the student researchers.

The three-year time span of the THRIP agreement (and funding) is causing much of the urgency in the network, but it also sets a difficult deadline, particularly when there is reliance on student researchers. Against this must be weighed the strong commitment of the partners to the knowledge aspect of the network, and the great commercial potential of the project. This suggests that research on starch-based polymer compounds will continue in another form if the current project is not successful. If it is successful and a product is commercialised, the network will move onto another level.

Interactive learning and other intangible benefits

The partners in the phenolics network have benefited in very material ways. Merisol has had much of its R&D conducted by the higher education institutions, as well as broadening its learning interface, and the higher education institutions have received funding to conduct important research. However, to date the network has not developed technology or a product that has been commercialised, although Gradchem are in the process of commercialising a spin-off technology developed by PETCRU.

There is widespread acknowledgement of other, less tangible, benefits. All the respondents described their involvement in the network as a 'win-win' situation, and said that if this were not the case, the network would not survive. While industry expands its knowledge base and competitiveness, the higher education institutions are able to purchase more sophisticated equipment, attract more students with bursaries and guaranteed job opportunities, and create a more productive learning environment through the knowledge generated in the network. Some argued that the partners do not necessarily benefit equally in the early stages of a network, but that there is a tendency for the benefits to increase and even out as the network develops over time. For example, the technikon and university were seen to have acquired an increasingly larger share of intellectual property rights as the relationship consolidated over time.

The academics saw the benefits as extending beyond solving immediate problems to developing new understandings and new avenues of exploration. It was recognised that many of the benefits are indirect, often not measurable, and mostly visible retrospectively. The industry respondents indicated, for example, that they save a lot of money in training costs by employing students who were involved in the research projects of the network. There is, moreover, a process of interactive learning that occurs within networks over a period of time. This learning process involves both scientific synthesis of multi-disciplinary knowledge and the acquisition of skills in the management of collaborative networks. Such intangible benefits create a virtuous circle that further strengthens the network.

The first formal contract between Merisol and PETCRU contained a stipulation that unless a commercialised process or new business was generated within five years, the interaction between the two would terminate. In the years since the agreement was made, commercialisation has been the primary objective. In terms of the founding agreement, therefore, a strong possibility has existed that the formal relationship between Merisol and PETCRU would end. Whether Merisol will stick to the agreement is not certain. First, it is apparent that considerable benefits have flowed from the network. Second, the network is varied and complex, and has gained a momentum that suggests it will continue and expand rather than end. So, while the foundation agreement possibly puts a limit on the future of the network in its present form, it is, particularly with the inclusion of Chemin, likely to continue in some other shape in future.

Benefits of the networks: future prospects

Formally, all of the cases have a fixed lifespan specified in their agreement – the period of the master's studies, the three-year THRIP agreement, and a five-year window within which to commercialise an innovative technology or product. None of the networks has achieved their primary objectives and, at the time of writing, deadlines were looming for all.

All three projects have made considerable progress – prototypes, experimental outputs, commercialisation in process – but, more importantly, they have all generated new knowledge. The benefits of such knowledge are generally impossible to quantify and often difficult to specify. In some cases these are indirect and will be realised only over time. The generation of knowledge, fundamental and applied, is clearly of benefit to higher education partners, but was also highly appreciated by the industry partners.

Both the contract partnership and the two networks have produced multiple, mutual benefits, tangible and intangible both, for all concerned. The possibility of the research achieving a breakthrough, and commercialisation taking place, still dangles like a carrot in front of all the partners. Moreover, all of the networks have functioned smoothly, primarily as a result of strong personal ties and mutual trust, but also because of the growing knowledge that the partners have about interacting within partnerships. The organisational limitations and imperatives of both firms and higher education institutions do, however, result in some of them being difficult partners. Tensions are in the nature of networks built on mutual interdependence, and are not necessarily destructive. The relations between the partners and their common interests constantly balance and accommodate the structural differences.

So, while there is no guarantee that any of the networks will continue, the benefits that have flowed from the networks, and the potential benefits that could still be realised, seem to outweigh the costs and the few problems that have been experienced. In each case, much will depend on the industry partner and the nature of the research. The need for external R&D capacity and the policies of the main industry partners, suggest that the starch-based plastics and the phenolics network will continue, albeit in different configurations. If they continue, it is likely they will expand to bring in different expertise required in the research.

The power of industry partners in new materials networks

The cases provide important insights into the determinants of the structure and the functioning of networks, particularly when the marked differences between the contract partnership and the two networks are contrasted.

The very large size of the all the industry partners is characteristic of the new materials development field. It is argued that the root of the difference lies in the strong position of the main industry partners, and that their competitive strategies, R&D infrastructure and R&D policies, as well as the nature of their core process, have to a large extent determined the structure and functioning of the partnerships.

In the case of the recovery of metals partnership, Anglo Platinum is very big; it has a large R&D facility and a culture of developing its own knowledge; and it is extremely secretive about this knowledge. The research focuses on an existing upstream recovery process and is driven by a strategy aimed at reducing costs and growing market share. Anglo Platinum's approach to the partnership is characterised by narrowness: the research project is narrowly focused, the number of partners is limited, and there are restrictions on knowledge transfer.

The industry partners in the other two networks have played an equally powerful role in the way in which the networks came to be structured and how they now function. Their lack of R&D capacity; their policy of engaging with external organisations to develop innovative technologies; and their focus on expanding downstream applications as part of a value-added competitive strategy to grow the market for particular products, have all influenced the architecture and dynamics of the networks. In these cases, the asymmetries in power have not translated into hierarchical governance, the research process has been more expansive, knowledge has been shared equally, and the networks are developing and growing according to the needs of the research.

A related explanatory factor is the gap between research and commercialisation: the amount of research and other preparation that still needs to be done to commercialise a process or product. In the case of the contract partnership, the research focuses on an existing process with a view to improving or refining it, and any improvements could be quickly translated into cost savings. The networks would require major investments in plant, equipment and marketing as well as the development of production processes to move to commercialisation. The size of this gap influenced the way in which the industry partners approached their engagement with higher education institutions and industry intermediaries: on the one hand, a very narrow engagement and restrictions on knowledge transfer, and on the other hand, a more open and expansive approach.

However, it would not do to give an impression reducing networks to merely an outcome of the interests of firms and their competitive strategies. Such a view would be overly deterministic, placing too much emphasis on industry structure and markets. Networks are deeply influenced by social relations, by norms and values such as trust and respect, and by context. Furthermore, networks have a history and develop over time, reshaping themselves as they seek to accommodate interests and pursue new research directions.

Power, whether explicit or implicit, is an essential element of the relations that characterise networks. It is not necessarily a negative factor – it can act as a binding force as well as play a dynamic role in leading a network in new directions. The power of industry partners is therefore only one aspect of the complex sets of relations and interests that make up networks. In these three new materials cases, it is evident that the power of the industry partners has been a strong influence on the way in which they have come to be structured and function. However, there have been many other factors that have mediated the way in which the industry partners engaged in the networks and exercised power. It was demonstrated above how the interests of intermediary partners such as the CSIR and THRIP, strong collaborative ties rooted in common research interests, as well as long-standing personal relationships, all influence the way in which power is balanced within the network.

The relative sophistication and complexity of the networks suggest a longer-term future than would be likely for narrow and limited networks. Whether this is indeed the case requires that more attention be given to the life of networks over extended periods of time.

CHAPTER 5

'Learning' through networks in South Africa

Glenda Kruss

Higher education institutions in South Africa are challenged by the new science and technology policy framework to create research networks and partnerships with industry, and to contribute to growing a national system of innovation. This monograph has attempted to explore in detail how the network – a new organisational form typical of the knowledge society – is currently being created in practice, in all its complex and messy reality, in three high technology fields.

It is worth repeating the caution that the eleven cases presented in the previous chapters are not representative of the total spread of networks in South Africa. Moreover, not all the cases were at the same level of maturity, which clearly complicates our understanding of the creation of networks. Some of the differences between them may be accounted for by the different stages of development of the networks at the time of the research – recently initiated, long running, or nearing the end of a formal commitment. Nevertheless, given the level of detail and depth of analysis, it is possible to draw out general insights from the cases about the ways in which networks are currently being created in South Africa.

The cases illustrate the partial and uneven nature of transition in South Africa, and the co-existence of old and new organisational forms as new policy directions unfold. Not all the cases initially included in the study as instances of networks are, in fact, structured and operating as networks. At least one of the cases represents the old form of a contract partnership. A few of the cases represent 'proto-networks': despite their formal constitution as a network, they tend to operate within the bounds of a dyadic relationship, or within the bounds of a single node, whether higher education or industry. And a number of the cases do display clear features of the new organisational form of the network operating in industry and in higher education.

The cases also illustrate the contingency and embeddedness of networks based in research entities in universities or technikons, or in distinct knowledge and technology fields in South Africa. They show that networks may be driven by the concern of enterprises in an industrial sector to enhance competitiveness through the innovation of upstream or downstream products or processes. Co-operation in the network may be pre-competitive, or may be focused on commercialisation. A network may be driven primarily by large companies or by SMMEs, or the locus of control may be more firmly situated in a university or technikon seeking to create new products and markets. It is not possible to make generalisations about whether networks are more likely to be driven by industry or by higher education, or by large or small firms, or in relation to pre-competitive collaboration, and so on.

Above all, these cases illustrate the complex ways in which the structure and the nature of networks are shaped by the contexts in which enterprises and research entities operate – whether collaborating in biotechnology, ICT or new materials development. The cases highlight the richness and variability of higher education responses to contemporary challenges.

To sum up, the empirical evidence of the case studies suggests that the creation of new organisational forms of knowledge networks in South Africa is shaped by multiple interdependent determinants, operating simultaneously. The following section explores these dynamics, and the chapter goes on to draw out, from these cutting-edge trends, insights for government policy and for the higher education sector.

Understanding networks in high technology fields

The question was raised: 'What are the variations or commonalities between networks operating in the three technology fields?' Analysis suggests that there are far greater commonalities than variations evident in the complex determinants of networks. These will be discussed in the next section, followed by a brief consideration of the degree of variation evident.

Multiple layers of determinants

Drawing from the analysis across the three fields, it appears that what shapes the creation of knowledge networks in South Africa is primarily the competitive dynamics of the industrial sector. The cases illustrate that, in order to appreciate what drives or constrains industry to seek research networks, it is critical to understand the industrial sub-sector within which an enterprise operates. This involves the dynamics of competition operating, and the centrality of research and innovation to a company's competitive strategy or its insertion in a 'value chain'. These dynamics differ with the maturity of the industrial sectors, of the technology fields on which they draw, and of the supportive policy context within which they operate. The conditions created by government policy-steering mechanisms to promote science and technology, innovation and partnership, particularly in the three high technology fields, impacted in various ways on what was possible (see below).

Whether the research relates to upstream or downstream products or processes, and whether the innovation involved is new to the world or new to South Africa or simply new to a specific enterprise, is a key determinant. Knowledge networks are created when enterprises – large or small[1] – are willing to enter into co-operative alliances with higher education (and intermediary) partners, to meet their complex knowledge and technology needs, in order to enhance future competitiveness of their product or process. Knowledge networks can also be created when entrepreneurial academics enter into co-operative alliances with higher education, industry and intermediary partners to meet their complex knowledge and technology needs, in order to commercialise their knowledge products. Klerck phrases it very well in Chapter 2 when he says that the dynamics of competition in a particular product market or industrial sector are closely linked to the dynamics of co-operation found in technology co-operation networks.

Of course, the knowledge and technology needs of an enterprise do not shape the structure and dynamics of a network alone. Rather, they intersect with the levels of expertise in higher education, in terms of the existence of a 'critical mass' of academics in a research specialism, and equally, with the tacit knowledge of managing research

1 Firm size is commonly believed to influence the nature of networks, but the evidence from the cases investigated supports Audretsch's (2003) argument that the relative innovative advantage of small and large firms varies across industries. He shows, however, that the evidence increasingly suggests that strategic partnerships may be more important for smaller firms than for larger corporations with access to their own R&D facilities. In the South African case, 66 per cent of THRIP industry partners in biotechnology were SMMEs, in ICT 58 per cent, and in new materials projects 51 per cent (HSRC 2003).

partnerships with industry. Again and again the cases show that this is usually embodied in an academic entrepreneur, who is the linchpin in ensuring the connectedness of the network. Closely linked is the significance of centralised institutional support – financial, legal or administrative. Higher education institutions with strong research expertise and management structures appear to be more effective in supporting academics in the creation and maintenance of networks.

The involvement of an intermediary partner, drawn from the public sector in a range of ways, provides a further layer of complexity which may intersect to determine whether a network is created and, if it is, the structure and dynamics of its functioning. These intermediaries take a number of forms. Actively involved in funding, knowledge generation or even commercialisation, were market-driven government science councils. Government departments or agencies such as the WRC were involved in directly funding and shaping the trend of research, or even in mediating relationships within the network. More passively involved, in funding only, shaping the formal structure of networks, were government funding programmes such as THRIP, the Innovation Fund or Godisa incubator schemes, and international government agencies with bilateral agreements.

The intersection of interests – or consistency – gives all partners a stake in the research project at the heart of the network, and builds the levels of trust required for it to 'work' or 'succeed'. It was evident that although many of the networks studied were yet to realise their goal of delivering a finite innovation of product or process, networks can lead to substantial benefits, in the form of increased profit for industry, an improved research profile for higher education, and wider socio-economic benefits. A key intangible benefit for both industry and higher education was broadening their organisational 'learning interface'. Conversely, conflict and tension were evident within those networks that were not constructed on the basis of sufficiently sound organisational 'learning', particularly as the point of commercialisation was approached.

Networks in the three high technology fields

There is a degree of variation evident between networks in the three high technology fields, related to the maturity of the industrial sector and of facilitative policy mechanisms. The variation is strongly evident in the analysis in each of the three chapters, and will merely be summarised here.

It was argued that new materials development is a more mature field than biotechnology and ICT in South Africa, which were described by some as 'pre-competitive'. Government policy and financial support for the sector was cut in the early 1990s, leading to a loss of research capacity and fragmentation but, at the time of study, there were signs – with the development of the Advanced Manufacturing Technology Strategy – that the situation was beginning to shift. There were exciting instances of network collaboration around fundamental and strategic research for expanding downstream applications of a primary resource, to create new markets. At the same time, however, there were signs that old contract forms also continued to operate, in ways that were not entirely beneficial to the higher education partner.

Biotechnology in South Africa is historically well-established in first- and second-generation activities, with little industrial development drawing on third-generation technology – but a strong government commitment to build a bioeconomy, as part of a national strategy for enhancing global competitiveness. Here we found considerable attempts, incentivised by government schemes, to collaborate around strategic research leading to commercialisation, as well as pre-competitive research to improve the quality of upstream products and processes. The locus of control lies more strongly in the university itself – given the relatively small size of the emerging industrial sector in South Africa, and the nature of the global bioeconomy, which has its roots in technology transfer and spin-offs from university and science council laboratories. The active role of government intermediary agencies encouraged and facilitated research co-operation in the public interest or with a strong development mandate.

The ICT sector tends in general to import and adapt technologies that are new to South Africa, rather than to engage in cutting-edge research and development of new products or processes. Indeed, analysis suggests that network evolution in the ICT industry in South Africa as a whole is relatively immature. There were cases with a commercialisation thrust similar to that of the biotechnology cases, but in the other cases the core of knowledge exchange tended to centre around a dyadic partnership and applied research. Although these cases display the formal features of a network, in practice they exhibit only a small degree of connectedness and consistency. Importantly, based on the success of the collaboration, future strategic and fundamental research is likely to be conducted within a more actively complex knowledge network. These partnerships may thus be more accurately described as 'proto-networks', and may lay a significant basis for organisational learning and future networks.

Such are the multiple interdependent determinants shaping the creation of knowledge networks. What are the implications for policy and practice highlighted by the analysis? What are the key issues and problem areas they suggest need to be taken into account, in order to create knowledge networks in South Africa, on a wider scale? How can the analysis inform the responses of higher education to contemporary challenges? These issues will be considered in the following sections.

Implications for a developmental strategy

The development path chosen in South Africa is one of state regulation and steering, drawing on the example of the social democratic countries of the West and the newly-industrialised countries of the East. By balancing the strategic role of the state with prevailing market forces, proponents argue, co-ordinated market economies have more successfully established institutional, infrastructural and interlocking policy requirements. These can then underpin both equitable social development and successful incorporation within the global economy. Adopting such an approach means that the South African state aims to rule in an indirect and flexible way through a regulatory framework of incentives and disincentives, which aim to steer the economy in strategic directions and co-ordinate state policy across a wide range of levers. Single reforms are not sufficient; interlocking, complementary policy measures are required.

New science and technology policy in South Africa is underpinned by such a regulation and steering approach, evident in the emphasis on cross-sectoral state policy co-ordination under the strategic leadership of the Department of Science and Technology. The 1996 White Paper on Science and Technology has as one of its aims:

> …to highlight the relationships between the different mechanisms of delivery of services to our people, and to outline the way DACST can play a co-ordinating role in effective and efficient implementation of interventions…Equally, the national innovation policy must be carefully articulated with other overriding policies of government. (DACST 1996: 5, 6, 18)

The national Foresight Study (DACST 2000) that identified the development of capacity in ICT, biotechnology and new materials development as priorities, is a further example of government policy commitment to cross-sectoral policy co-ordination. The National Research and Development Strategy (DST 2002) aims, amongst other things, to mobilise the private sector, research organisations, venture capital and higher education to 'deliver innovation through the technology missions'. Chapters 2, 3 and 4 described the interlocking sets of regulatory policies, strategies and steering mechanisms developed by multiple government departments and agencies, explicitly intended to support research and development in specific fields, and the growth of a vibrant national system of innovation.

Essentially, the analysis of the cases illustrates the unevenness of policy implementation and change – partly a result of the short time period since the inception of key government initiatives. At the time of the empirical research in 2003, it was less than ten years since the 1996 White Paper on Science and Technology had laid out the policy framework, less than a year since the formulation of the 2002 national Research and Development Strategy and national Biotechnology Strategy, and less than a few months since the 2003 proposal of the Advanced Manufacturing Technology strategy. Key levers for incentivising partnerships had, however, been in place for longer. In the case of THRIP, this has been since 1995/6, and for the Innovation Fund since the 1997/98 financial years. Hence, what the cases reflect is the ways in which some higher education and industry researchers at the cutting edge are responding to changing imperatives, in a fairly unregulated manner. At the same time, the analysis allows us to highlight some of the possibilities and constraints evident in the current policy context.

Problematising the notion of innovation

Understanding the variable nature of the knowledge and technology needs of enterprises, and the complexity of the network ideal, led us to problematise the notion of 'innovation' itself. The definition adopted for the study was that of government policy as explained here:

> [the] application in practice of creative new ideas, which in many cases involves the introduction of inventions into the marketplace. In contrast, creativity is the generating and articulating of new ideas. It follows that people can be creative without being innovative. They may have ideas, or produce inventions, but may not try to win broad acceptance for them, put them to use or exploit them by turning their ideas into products and services that other people will buy or use. (DACST 1996: 15)

The international comparative literature suggests that we can distinguish between product and process innovation (Klerck 2003); while Itzkin (2000) suggests that within each there are three degrees of innovation, involving increasing degrees of change: incremental, synthetic and discontinuous. The greater the degree of change, the more knowledge-intensive the collaboration is likely to be, and the greater the learning required by both individuals and organisations.

Product innovations most typically involve incremental change, taking place continuously, and leading to new versions, adding features or extensions to an existing product that will enhance competitiveness. Existing knowledge is combined in creative ways to produce significantly new products in a synthetic innovation, and discontinous product innovation entails the development of truly novel technologies. Similarly, most process innovations are incremental, to enhance the quality or decrease costs of a process of manufacture or service. Synthetic process innovations increase the output and efficiency of existing production processes, while discontinuous process innovations lead to completely novel production processes. Complex, discontinuous innovations, whether of process or product, can rarely be produced without networks, collaborative partnerships or strategic alliances.

There were clear-cut cases in the study of potential synthetic innovation of product, such as the virtual environment tool, and cases of potential synthetic innovation of process, such as the tools developed in the bioinformatics project – genomic information, computational biology and analytical. There were, however, many more cases of incremental innovation – particularly those coming from technikons – that appeared to be improvements on existing technology, or adaptations of technologies developed elsewhere in specific South African or regional contexts.

However, the potential outcome of certain projects can mean critical innovation in the South African context. An example is the capillary ultra-filtration system, which could have a widespread impact on the quality of life of many, particularly those living in rural areas who have not had adequate access to water resources. Does innovation have to be a 'big bang' development that changes the face of a knowledge field, and of an industry standard to be valued? Is a small incremental innovation with potentially far-reaching social and economic implications not as significant, or perhaps even more significant, in the South African context?

Lorentzen et al. (2005: 1) provide a useful distinction for understanding innovation in a country like South Africa:

> In essence, a product or a process may be new to the world or to a subset thereof – a continent, a country, a region, or even an individual firm. Only in the first case are we concerned with the creation of information *ex novo*, for example a new vaccine to treat tropical diseases. In all other cases the innovating entity does not reach for the blue sky but engages in an activity that is new (only) to itself.

Lorentzen et al. make the point that for improving the quality of life, diffusion of knowledge is often more important than creating knowledge new to the world, or what Itzkin calls 'discontinuous innovation'. This is particularly the case in a developing country like South Africa, where we may need research on a product or process that is new to the country, or to specific regions, or firms. The mychorrhizal network, with research on potential applications of indigenous AMF in five regions in a wide range of agricultural sectors, is an instance of such a process.

The cases thus suggest that, firstly, we need to foreground a more expansive and nuanced definition of innovation. Research and development strategy is committed, as one key thrust, to science and technology for poverty reduction in the interests of the most marginalised, and, as another, to identifying new technology platforms in line with global trends. The cases dealt with here are a reminder of the wisdom of this approach, and the need to balance the two. Our notion of cutting-edge innovation should include the social good, as well as a wide range of innovation, not only research-oriented to high technology global competitiveness and discontinuous innovation that is regarded as cutting edge in its field, or perhaps even new to the world. It is important for the goal of promoting a South African knowledge economy that policy makers and higher education managers value the entire spectrum of innovation – from that aimed at benefiting a specific company to that which operates in the public good, and from that which yields high technology artefacts and processes to that which yields low ones.

The cases discussed provide important insight into the relationship between networks and the promotion of innovation. Incremental innovation, new only to a specific firm, may arise out of contract or consultancy forms of partnership and does not necessarily require a network. There is, however, considerable evidence from this study that such contracts may be an important step in organisational learning, as an industrial sector matures. A partnership is more likely to be of wider use in the industrial sub-sector related to a specific firm if it arises out of a network. The optical fibre research that can contribute to enhance the quality of the communications infrastructure of the entire sector, is one example of the value of the collaboration and co-operation inherent in the network form of organisation. Significantly, the project operates to the benefit of the higher education partner by developing a new field of research expertise, attracting students and generating knowledge and publications. The new organisational form of the network is thus essential for bringing partners at each node together in a way that will lead to innovation – incremental, synthetic or discontinuous – and economic growth, but at the same time, further advance the goals of higher education. Otherwise, higher education researchers may be creative, without being innovative – putting their ideas to use – and firms may use higher education's knowledge for their own limited gain.

Understanding the complexity of innovation can thus inform cross-sectoral co-ordination of interventions within the national system of innovation, and within higher education institutions, that are grounded in the demands and realities of the South African context.

The need for a more nuanced and targeted approach

The cases examined here provide evidence of the significant role played by multiple government departments and agencies as intermediaries in shaping the creation of networks through providing a range of incentives. A key implication of the analysis is that, for a developmental state to play a more expanded role in facilitating networks, public sector stakeholders require a more sophisticated and informed analysis of where they can make the best impact. Higher education leadership, policymakers and officials in the Departments of Education, Science and Technology, Trade and Industry or Water Affairs and Forestry all need a more grounded understanding of how they can best harness their resources to steer the higher education system – as part of a national system of innovation – towards the desired goals. The complex intersection of industry, higher education and intermediary interests in shaping knowledge networks suggests that we need to understand in greater depth the 'embeddedness' of institutions, particularly of enterprises, to inform cross-sectoral steering measures.

Targeting a 'reluctant' industry

There is little doubt that the government funding available in the form of THRIP or Innovation Fund grants contributes significantly to the willingness of industry – and of higher education – to initiate or enter a partnership (see also HSRC 2003). However, whether these partnerships take the form of knowledge networks – or of other forms of partnership, such as contracts – is a complex issue that deserves more exploration. Funding programmes may incentivise partnerships, but do they promote enough of the *kind* of partnerships that can be of maximum benefit to all partners involved, and lead to innovation?

There has been a widespread perception amongst academics that 'industry' is reluctant to initiate partnerships with higher education beyond those that are short-term and meet industry's immediate technology needs (Kruss 2005). There is a sense in which such a perception is borne out by the cases. Some of the THRIP-funded networks operated as proto-networks with a dyadic partnership, and some of those funded by the Innovation Fund operated with little knowledge exchange or collaboration between industry and higher education. Some of the networks initiated by a higher education partner had struggled to obtain sufficient interest and financial support from potential industrial partners for their commercialisation efforts, and with varying degrees of success. The biotechnology and ICT commercialisation cases in particular revealed a high degree of reliance on government funding with little industry commitment, which the analysis suggested may not be optimal in facilitating knowledge networks.

The reluctance of industry to make a greater commitment suggests that, if left solely to the imperatives of the market, networks may not develop, and that the state's steering role is thus of key importance. We need to strengthen strategies that can convince reluctant industry partners of the value of research collaboration and knowledge networks.

Better information systems to promote a larger scale of knowledge networks

The central point argued here, is that what we have currently is a set of relatively blunt incentivisation instruments that have been in place for only a relatively short period of time. They enshrine the principle of promoting partnership between industry and higher education. We need a variety of types of industry partnerships across the higher education system, to meet different purposes. These can lie anywhere in the range from consultancies and contracts to full networks. But to meet national developmental policy goals, as well as ensuring the future knowledge-generating capacity of the higher education sector and its ability to contribute to a national system of innovation, we need specifically to increase the *scale* of knowledge networks. To do this we need a more nuanced understanding of the embeddedness of the potential partners situated in the multiple institutional nodes. On this basis we can develop more targeted, co-ordinated steering mechanisms to intervene to encourage industry in particular, but also higher education partners, to construct knowledge networks.

For this to occur, we need a far better set of cross-sectoral management information systems than is currently available. Lorentzen et al. (2005) suggest that the empirical base for assessing the extent to which government cross-sectoral initiatives complement one another to steer the national system of innovation in the desired policy directions, is currently insufficient. This claim is borne out by the analyses of a number of other researchers (Adam 2003; Boshoff & Mouton 2003; CHE 2004; NACI 2002).

What are the kinds of research and information base suggested by the analysis of the cases that could support more targeted cross-sectoral initiatives to incentivise networks and partnerships? How can they inform the key role of government, in a developmental state, of gathering and disseminating information to steer change in desired policy directions?

First, on the demand side, there is the need for a stronger research and information base, on a sectoral basis. The analysis of the primary determinants of networks emphasises the value of and need for more systematic sectoral studies, of understanding specific product markets and competitive strategies. It highlights the value of and need for understanding patterns of diffusion of new technologies, and of work organisation, and their associated skills demands within the enterprises in a sector. It also highlights the need to consider data on new market opportunities for growth and export. The importance of spatial proximity in the constitution of the core of networks reinforces the significance of understanding such trends – not only at national level, but also regionally, to understand regional and local sectoral strengths and innovation potential. To date, we have little understanding of how industrial sectors develop on a spatial basis, in any specific province or region. It may be that such data exists, within a single government department. In that case, what is needed is dissemination mechanisms to allow the data to be utilised in a meaningful manner, and informing the work of other stakeholders.

Second, on the supply side, we have a fairly sound understanding of basic trends (see for example HSRC 2003), but as Lorenzten et al. (2005) argue, there is a need for a more sophisticated analysis of the supply of human resources in the national system of innovation. For instance, the analysis of the cases suggests the value of understanding patterns of higher education graduates, particularly at the masters and doctoral levels, in fields related to key industrial sectors. We need to understand how the funding levers and incentives of the National Research Foundation and the Department of Education can complement each other in the support and provision of high-level human resources in key fields that may be identified for support. This is particularly the case now that the NRF has adopted a 'seamless approach' of research support across the spectrum, integrating its programmes from basic postgraduate research funding to the point of technology transfer and commercialisation (see www.nrf.ac.za/profile/nrfbusinessplan.pdf).

Thirdly, it would clearly be useful if we had a comprehensive database with details of the existing partnerships between industry and higher education, and the incentives that support them. This would enable us to track progress over time, and monitor the responsiveness of the system.

The point is thus not that cross-sectoral awareness does not exist, but rather that it needs to be deepened. One important requirement is better information for managing steering levers across and between different government and higher education agencies more effectively and efficiently.

Strategies for facilitating networks

We need strategies to facilitate knowledge networks on a larger scale in South Africa; for the long-term benefit of the higher education sector, for the benefit of the enterprise and industrial sector, and for the benefit of socio-economic development. The analysis described in this work suggests that we need to draw on more sophisticated databases to identify more effectively which higher education institutions and which industrial sectors need stronger public sector leadership and cross-sectoral interventions, and what form these interventions could take.

Understanding the embeddedness of the research and technology needs of specific industrial sectors may inform more refined ways of expanding the reach and coverage of intermediary agencies such as THRIP and the Innovation Fund. Or it may suggest better targeted ways in which incubator schemes can draw more SMMEs into innovation programmes. It may allow better co-ordination of the mechanisms and programmes adopted by the Department of Trade and Industry and the Department of Science and Technology for instance, with the programmes of the Department of Education, to promote research in the higher education sector. It may inform regional innovation strategies, in the light of growing evidence suggesting that we need greater involvement of agencies at provincial and local government levels, to strengthen innovation based in regional clusters.

The study thus suggests that we need to open up the ideal, already enshrined in government policy, of the desirability of partnerships between higher education and industry, to more empirically informed analysis of the complexity of creating networks. Understanding what drives specific companies in specific industrial sectors to seek partnerships with researchers in specific universities and technikons can facilitate cross-sectoral co-ordination of interventions within a national system of innovation.

Such an understanding is equally significant for research managers and leaders in higher education institutions, to facilitate cross-sectoral interventions across the higher education system. Individual institutions need to develop their own internal institutional co-ordinating strategies and mechanisms, to promote network forms of partnership across a greater spread of their research entities. And higher education associations such as the Southern African Research and Innovation Management Association (SARIMA) and Higher Education South Africa (HESA) need to co-ordinate strategies more effectively. What are the implications of the analysis for the strategies and practices of higher education? How can higher education institutions learn from this analysis, to deal with contemporary challenges? The final section will present some potentially useful directions that we can pursue.

'100 universities require 100 solutions'

The work of Clark (2004) problematising the 'entrepeneurial university' provides a number of significant ways of approaching the implications of the present analysis for the South African higher education sector.

Clark argues that, for universities to respond to the multiple challenges posed by government, industry and social groups, the key is to, 'develop flexible capabilities that permit them to weave together new and old, change and continuity, in sustainable form' (2004: 1). Not unlike the logic of the present analysis, his work draws on case studies of higher education institutions that appear to be successful in changing along these lines. He argues that we can only draw out general insights based on understanding the, 'embedded realities of university life' (2004: 2).

Here we have focused on one key challenge facing higher education – the demand that research should become more responsive and contribute more to innovation and economic development, through research partnerships with industry. And like Clark, we have argued that by exploring in detail cases appearing to be successful in creating networks, and that balance the interests of higher education, industry and government partners, we can draw out insights for higher education institutions.

This monograph has attempted to show that we have to understand the uniquely South African innovation and industrial context within which higher education will need to engage. It is evident that, for higher education institutions, there are many structural constraints in the economic and industrial landscape over which they have little control. This is manifest in the reluctance on the part of many of the firms surveyed to shift to knowledge-intensive competitive strategies and, importantly, to incur financial risk. Government's policy and programmes may ultimately have some impact on shifting these conditions, but it is as yet in its initial stages and, as the study illustrates, we have no guarantees about the ways in which intended policy will take root in practice.

Indeed, Clark argues that the state-led, system-centred and top-down pathway is not the most appropriate for bringing about change in the kinds of complex higher education institutions we find in our contemporary context. This, he argues, is because, 'system-wide changes are notoriously slow in formation and blunt in application' (2004: 182). State-led change often takes the form of a 'one-size-fits-all' policy, treating all higher education institutions as if they are the same, which tends to lead to the kind of homogenising mission drift that is threatening to emerge in South Africa, despite a policy commitment to differentiation.

Echoing such a concern, the monograph has argued that we need to understand the knowledge, technology and competitive needs of specific industrial sectors as they relate to specific technology fields. Through a detailed analysis of networks, the research has demonstrated the embedded nature of the network structure and dynamics, and, although there is a long way to go in most cases, it has shown how there is no single 'best-practice' path to innovation success. It was thus suggested in the previous section that state attempts to steer the system and bring about change need to be informed by such specificity; to become more nuanced and targeted.

Clark goes further, to argue strongly for an institution-led, bottom-up pathway to change, based on the principle that, 'complex universities operating in complex environments require complex differentiated solutions. One hundred universities,' he says, 'require 100 solutions.' (2004: 183).

Clark (2004) argues that what has changed in current conditions is that complex universities are engaged in market-type relationships on a far greater scale than previously and – significantly – they differ in the amount of control they are able to exert. The most critical dynamic, he claims, is that institutions need to develop the capacity to adapt rapidly to change. The greater the capacity to adapt rapidly to change, the greater the control an institution is able to exert, and hence the more likely it is to be able to compete nationally and internationally. Clark argues for a policy pathway that encourages institutions to draw on their strengths and constraints, to create their own solutions, combining the old with the new. He poses a challenge to universities to look within themselves to sustain and develop their capacity for changing in response to challenges, and to the capacity for change.

Chapters 2, 3 and 4 illustrated in detail the ways in which different universities and technikons have created internal policies, structures and mechanisms that facilitated or constrained the creation of networks, reflecting their capacity for adaptive change. In a companion HSRC study that mapped partnership across the higher education system in South Africa, we identified types of higher education institutional approaches to partnership. It was argued that only a few universities have the research capacity and the institutional policies, structures and mechanisms to be able to harness their potential for innovation, and these universities are more likely to house the new organisational forms of networks (Kruss 2005). Another few institutions show evidence of an emerging entrepreneurial approach; a large number have adopted a laissez-faire aspirational approach, and a fourth group display a laissez-faire traditional approach to industry partnership. These universities and technikons may typically display isolated instances of networks that are the initiative of individual academic champions.[2] The argument

2 A sizable group of institutions do not possess sufficient research capacity in science and technology fields at the present point, but should their capacity develop, they are likely to fall into one of these four broad categories.

was made that a greater number of higher education institutions across the system need to develop the capacity to harness the potential for innovation – to enhance global competitiveness or to contribute to rural socio-economic development. The call is for more higher education institutions to develop a strategic response to the new imperatives.

There is thus considerable substance to the argument in favour of higher education institutions adopting a bottom-up approach to change, alongside the top-down approach of state steering. Institutions require sophisticated analyses of their own capacity in relation to the demands of their context, in order to identify their own strategic solutions. What then are some of the insights from the case studies that can inform the development of such a flexible and adaptive approach to networks and partnerships in higher education institutions?

A delicate balance between fundamental, strategic and applied research

The new organisational form of networks in South Africa was found to be characterised by new types of knowledge production that are open-ended and flexible, and can accommodate fluidity. The goal of a network could be a specific product or process, but with multiple potential applications defined to varying degrees. Networks also had a less strongly defined product or process at their heart, and here a research collaboration had been established with multiple possible foci at different points in time that could further local capacity-development and support competitive innovation.

The cases illustrate that the partners at each of the three nodes have distinct knowledge and technology needs, and over time play different but complementary roles in the research collaboration. The networks involve considerable fundamental research with a long time-horizon, grounded in the higher education partners' laboratories. This research is likely to involve postgraduate students and may indeed have begun prior to the specific project. At the same time, other higher education or intermediary partners are typically involved in strategic research to specify parameters for possible future applications in specific settings. And simultaneously, but also building on the basic research, the networks tend to involve applied research for developing the required technology. This may draw on the expertise of the enterprise partner or other intermediary partners, such as science councils, with expertise that is not otherwise contained within the network.

The relationship is clearly not linear or sequential, with the research partner conducting fundamental research that is later applied by the enterprise partner. Rather, it is integrated in a complex manner, with different kinds of knowledge-generation assuming primacy at different points in time. Considerable difficulties were experienced in some of the networks that were not able to develop such flexible arrangements. For instance, there was direct competition between partners fulfilling the same fundamental research needs within a network, or else the focus fell primarily on fundamental research, with industry partners playing little direct role in the applied research and technology development. A key task of the network leader is thus the strategic co-ordination of these functionally separated but inter-related knowledge-production activities, which could require delicate balancing over the lifetime of the project.

As regards the different degrees of innovation, it was apparent that not all of the cases involved fundamental or strategic research but that a network could nevertheless be extremely innovative. Given their historical focus and their recent adoption of a research role, this was more likely to be the case where the research entity was based at technikons, or at newer universities with emergent science and technology capacity – for instance, in cases where the project focused mainly on final test trials for commercialisation of a system previously developed out of university-based research. Such a network brings together in synergy the analytical skills of university researchers and the applied skills of technikon researchers, in what was claimed to be a highly productive form of collaboration. These dynamics highlight the usefulness of the notion of 'complexes of activity' (Marceau 1996) operating at the higher education node. Clearly, simplistic distinctions between fundamental and applied research, or between university and technikon research are not useful, as they do not describe the reality of the inter-connections within networks.

The balance and inter-relationship between fundamental, strategic and applied research and technology development is a fine one, requiring careful management – and the development of greater expertise – on the part of researchers and of institutional leaders.

Organisational complexity

Related to the complexity of knowledge production, the cases illustrate that the internal structures of a network are fluid, with multiple layers of responsibility and authority operating simultaneously, with varying degrees of coherence between them.

At one level, there is the formal administrative and management structure of a network. Relations may be informal, but were typically governed by formal contracts, particularly in cases where an Innovation Fund consortium or THRIP partnership had been established. At a second level, financial responsibility is typically allocated to the lead research entity but it may be devolved to an intermediary partner such as the CSIR. At a third level were structures of project management, for monitoring progress and ensuring co-ordination between the research conducted by the partners at each node. And finally, there was a layer of technical management of the researchers within the entities at each node. The cases suggest that the more clearly the network structure was specified from the outset, with clear differentiation of multi-layered functions and roles, the greater the connectedness and the chance of reciprocity and mutually beneficial exchange within the network.

The varied network structure reinforces the usefulness of the notion of complexes of activity for defining the role and function of each node in the network. For instance, a complicating feature in defining the higher education node is the role of the applications partners. Are they secondary research entities integrally involved in the research, or are they structured into the network as intermediary partners? The answer to this must lie partly in the dynamics of the network, and the roles they play.

There is also complexity where an organisation that is formally based at a specific node may in fact be structured into the network with the function of a different node. In some networks there were instances of enterprises playing the role of a research entity in the knowledge-generation or technology-development processes, or of science council intermediaries playing the role of the link between the enterprise and the research entity. In other networks, the intermediaries acted as a development partner at the research entity node, or as a sub-contracting firm to provide missing expertise to the enterprise partner in technology development.

The formal location of an institution at a specific node is thus not a guarantee that it plays the role typical of that node, and functions are flexible between institutional sites. The cases suggest that, while the notion of three interacting nodes is a useful one, a neat and tidy notion is not evident in practice, but each node represents a 'complex of activity'. There is evidence of the increasingly fluid nature of the location of knowledge production, moving out of its traditional base in the universities, into science councils and enterprises. The concern for higher education institutions and research leaders is to identify strategies to harness the opportunities presented by this fluidity.

Managing organisational complexity

In highlighting the need to balance and manage the complexes of activity that frame the structure and dynamics of networks, the cases raised a number of organisational, institutional and managerial issues. A higher education institution may succeed in creating a network, but that does not ensure that the network will operate successfully and attain its goals. The effectiveness of the innovation process at the heart of a network is very much an organisational issue and depends on the individuals involved, the manner in which their creative activities are organised internally, and how they are connected with external institutions. Clearly, the dynamics of the network exchange are characterised by a number of intangibles. The following sections identify a number of issues, and raise questions about the ways in which organisational complexity can be managed, to promote effective networks within an institution.

The role of the academic champion in promoting trust and learning

The ability to manage a network is a 'problematic accomplishment' (Klerck 2003: 48) and not a given. The intangibles of social capital, and the relations of trust and reciprocity that underpinned network dynamics, were cited in virtually each case as decisive in shaping the success of a network. The partners at each node had different internal units, and their own objectives and pressures to co-operate. Tensions invariably arose between control and autonomy, and the centralisation and decentralisation of relations.

In the current South African context, the cases suggest, that the 'academic champion' who has learned how to manage network relations is central. This individual typically has a wide-ranging mix of academic reputation, research expertise and entrepreneurial skills – as well as a personality that can facilitate the trust on which the connectedness of a network relies. In some cases, it was suggested that the role of academic champion in the maintenance of network relations is so central that the network might not survive if that person were to leave. Other cases illustrated the opposite effect: of the absence of this mix of skills and the adoption of an overly academic orientation, which created problems for the effectiveness of the network.

Some networks displayed stronger evidence that key players and organisations had learned how to manage network relations, through past relations with industry or intermediaries. This was particularly true in networks which had roots going back into the apartheid science system, and which could draw on long-standing relationships to bring in expertise. This was also evident in universities that had developed supportive interface structures and expertise, to harness innovation potential. Managing a 'successful' network was held to demonstrate to university colleagues that industry partnerships do not necessarily mean a loss of academic independence or a compromise of scientific integrity.

Proximity and tacit knowledge transfer

Not unrelated to building trust is the issue of proximity. The literature suggests that knowledge production and utilisation tend to agglomerate geographically, to specific regional locations (Salter and Martin 2001). Proximity is viewed as an essential ingredient of network dynamics, given the importance of personal contacts, and the need to access tacit or non-codified knowledge. Increasingly, it is argued that the significance of personal contact is weakened by ease of communication technologies, lower costs of accessing knowledge, stronger intellectual property rights provisions, and the ability of firms to seek out knowledge anywhere in the world (Antonelli 1999).

Analysis of the eleven cases bore out such trends. Spatial proximity was most significant in networks that relied on a high degree of tacit knowledge depending on personal mechanisms for knowledge flows. Researchers in dispersed networks generally claimed to have mechanisms to overcome potential barriers, but expressed that it would be 'nice to have' more informal daily contact, which could enhance the research. There are clear instances of networks developing, based on specific expertise and past relations of trust built up through joint projects, despite geographical distance. However, in networks that appeared to involve researchers dispersed nationally and even internationally, often the partners active at the core of the network were situated in close proximity, allowing sharing of facilities, administrative support, key research personnel and key laboratories, which served as mechanisms of tacit knowledge transfer.

Commercialisation and intellectual property

A number of the cases had strong features of innovation through commercialisation – their goal was for higher education to exploit its intellectual property. Based on the power imbalances and potential for conflict revealed, the cases suggest that there remains a great deal to learn before commercialisation can succeed on a significant scale in South Africa.

University academics and managers are relatively weak in understanding the processes of negotiating the value of their research, and of converting their knowledge into a commercially viable product. As a result, relations of trust were easily strained as research processes came closer to commercialisation, and a negotiation of new relations of reciprocity and mutual benefit was required. In particular, decisions about the distribution of and entitlement to intellectual property rights tended to threaten the future stability of the networks, and their benefit for higher education. Network partners grappled with making the transition to an organisational structure that could support entry into the marketplace as a competitive enterprise. Critically, they also had problems with accessing the venture capital required. It is notable that in the shift from a research consortium to a commercially registered production company, the university location may be viewed as a constraint. Structural separation from the universities – few of which have specific institutional mechanisms to support commercialisation – was even considered. The situation was more positive where a university had strong, centralised, dedicated support for protecting and exploiting intellectual property rights. There may be evidence of institutional learning that has occurred over a long period of collaboration, demonstrated in the care taken to establish the formal structure of the network, underpinned by contracts.

Learning to manage networks

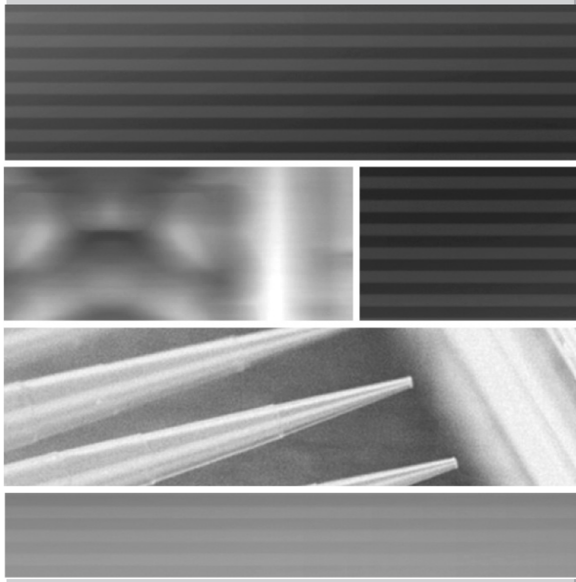
The inter-connectedness and embedded nature of network dynamics has been stressed. Particular practices cannot be isolated from their embedded contexts, as best-practice tips or guidelines. The inherent uncertainty surrounding the innovation process means that there can be no guarantee of a direct relationship between the amount of effort and resources that a higher education institution allocates, and the resulting outputs. In general, the cases highlight that innovative success depends on learning to understand, negotiate and manage a complex mix of government policies, competitive structures of industrial sectors, forms of work organisation, higher education approaches to and support for industry partnership, and the intangibles of culture, communication and inter-personal relationships. The crucial feature is the ways in which companies or research entities are *learning* to manage network relations.

One implication for higher education institutions is to consider the ways in which their research management and administration structures and processes can support academic entrepreneurs and research entities in operating effectively. Traditional forms of higher education institutional organisation need to be interrogated, to determine whether they inhibit the functioning of a network or provide it with effective support. In particular, the cases suggest that higher education institutions need to develop much more effective legal, financial, management and interactive learning expertise, to support commercial ventures in the institutional interest. Enhancing protection of intellectual property rights would also seem to be a key lever required for institutional and cross-sectoral government intervention. A critical aspect of organisational learning is more effective analysis by institutions of the opportunities available within their immediate regional location. There seems to be a great deal of scope for drawing on proximity of institutions to promote collaboration within regional innovation networks, as a lever to harness the learning capabilities developed within research entities and institutions.

Conclusion

The analysis of the eleven cases of networks has been offered to provide insight, as higher education institutions grapple with contemporary challenges. Clearly, some research entities and their institutions are developing the adaptive capacity to change, in the networks they create. But, according to Clark, the 22 new universities in South Africa will require 22 'solutions'. Each new university will need its own strategic analysis to develop its own embedded solutions.

This monograph has attempted to develop a new methodology for understanding the embeddedness of the relationships between industry and higher education in South Africa, in a way which can support the efforts aimed at change. There is a wide range of complex, inter-dependent and contingent conditions that need to be met in order to create and sustain networks that are beneficial for higher education institutions in terms of their core knowledge-generation role. Perhaps the insights offered here can form the basis for higher education researchers, and also leaders in their institutions, to engage with industry in a more strategic and targeted manner, exerting a greater degree of control over today's ever-changing and multiple demands.



APPENDICES

APPENDIX A

A comparative description of the eleven cases

	Focus of partnership	Partners at the higher education node	Partners at the industry node	Partners at the intermediary node
Biotechnology				
Water membrane	Commercialise an ultra-filtration system suited to developing country market	Water Membrane Technology Group, Durban Institute of Technology; Institute of Polymer Science, Stellenbosch University; Pollution Research Group, University of Natal	Amatola Water Board	Water Research Commission
Mycorrizhal	Develop process for large-scale production of AMF inoculants that increase growth, yield or fitness of plants	Potchefstroom University; Rhodes University; Witwatersrand University; Stellenbosch University; Pretoria Laboratory	Amphigro CC; field test partners, e.g., Chicory SA Ltd	Innovation Fund; Department of Agriculture/ Water Affairs
Bio-informatics	Develop bioinformatics software for gene detection and expression states	SA Bioinformatics Institute, University of Western Cape; European Bioinformatics Institute; Sanger Institute, Wellcome Trust	Electric Genetics	Wellcome Trust
Tree-protection	Upstream process to improve tree production by controlling pathogens	University of Pretoria; University of Natal	Mondi Forests; Sappi Forests; Hans Merenski; Global Forestry Products; Central Timber Co-operative	Forestry South Africa; Department of Water Affairs and Forestry
ICT				
Optical fibre	Upstream process to measure and monitor PMD, for quality control of fibre and cable products	Department of Physics and Telkom Centre of Excellence, University of Port Elizabeth	Aberdare Cables; Telkom; Corning (USA)	THRIP

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	Focus of partnership	Partners at the higher education node	Partners at the industry node	Partners at the intermediary node
ICT				
Free-space optics	Develop FSO system to enter market for flexible broadband data transmission	F'Satie Technical Institute in Electronics, Technikon Pretoria	Otex; Periseo	THRIP; F'Satie Technical Institute in Electronics
Virtual environment system	Develop authoring tool to enter developing country market for VE	Collaborative Visual Computing Laboratory and Contemporary African Music and Arts Archive, University of Cape Town	Video Lab; VIX	Innovation Fund (CSIR)
Multi-Sensor Micro-satellite Imager	Develop imager with applications in resource management, to grow market for low-cost, small satellites	Computer Control Systems Group and Electronic Systems Laboratory, University of Stellenbosch; Catholic University of Leuven (Belgium)	SunSpace; Defensetek; OIP Sensor Systems (Belgium)	Environmentek at CSIR; ISCW at Agriculture Research Council; Innovation Fund
New Materials Development				
Recovery of metals	Upstream process to enhance recovery of platinum	Centre for Electro-Chemistry and Centre of Material and Process Synthesis, Witwatersrand University	Anglo-Platinum	
Phenolics	Downstream processes and products, to grow market for beneficiation of phenolics	Port Elizabeth Technikon Catalysis Research Unit; Catalysis Research Unit, University of Cape Town	Merisol; Sasol; Merichem; Gradchem solutions	BioChemtek, CSIR; Chemin incubator; THRIP; DTI
Starch-based plastics	Downstream processes and products, to grow market for applications of corn-starch	Institute of Applied Materials, University of Pretoria; Network of European research institutions	African Products; Xyris Technology	Centre for Polymer Technology, CSIR; THRIP

Activities, by Standard Industrial Classification Code (SIC)

Table B1: The IT subsector (2001)

SIC code	Description	Number of companies	Percentage
86001	Software publisher	467	8.3
86002	Computer systems design and related services	191	3.4
86003	Computer facilities management services	169	3.0
86004	Computer and office machine repair, maintenance and support services	337	6.0
86005	Office machinery and equipment rental and leasing	33	0.6
86006	Customer computer programming services	669	12.0
86007	Other computer related services	3 683	65.8
86008	Call centre and customer relationship management system development	45	0.8
86009	Computer systems design services and integrated solutions	3	0.1
86010	Customer electronic repair and maintenance	0	0.0
86012	Communication equipment repair and maintenance	0	0.0
86013	Other electronic and precision equipment repair and maintenance	0	0.0
Total		5 597	100.0

Source: Isett online grant system, cited in Isett SETA (2002: 19 Table 1)

Table B2: The electronics subsector (2001)

SIC code	Description	Number of companies	Percentage
87143	IT importation and product integration of pre-manufactured electronics, IT and telecoms equipment	164	99.4
87146	Research and development in the physical and engineering sciences	0	0.0
87147	Electronics importation and product integration of pre-manufactured electronic, IT and telecoms equipment	1	0.6
87148	Telecoms importation and product integration of pre-manufactured electronic, IT and telecoms equipment	0	0.0
Total		165	100.0

Source: Isett online grant system cited in Isett SETA (2002: 21 Table 2)

Table B3: The telecommunications subsector (2001)

SIC code	Description	Number of companies	Percentage
75202	Television signal distribution	293	47.9
75205	Wireless telecommunications carriers (except satellite)	241	39.4
75203	Cable networks services	55	9.0
75201	Wired telecommunications carriers	12	2.0
75213	Cellular and other wireless telecommunications	5	0.8
75206	Radio and radio network signal distribution	0	0.0
75212	Paging	5	0.8
75214	Satellite telecommunications	0	0.0
75215	Other telecommunications	1	0.2
Total		612	100.0

Source: Isett online grant system cited in Isett SETA (2002: 25 Table 3)

APPENDIX C

Number of companies and employees, by company size within the Isett sector in 2002

Size		IT		Electronics		Telecommunications	
		N	Percentage	N	Percentage	N	Percentage
Small	1–4	4 486	80.2	111	67.3	534	87.3
	5–9	470	8.4	23	13.9	34	5.6
Medium	10–49	489	8.7	19	11.5	21	3.4
	50–99	64	1.1	1	0.6	4	0.7
Large	100–149	33	0.6	4	2.4	5	0.8
	150–249	22	0.4	1	0.6	0	0.0
	250–499	22	0.4	0	0.0	1	0.2
	500–999	5	0.1	5	3.0	6	1.0
	1 000+	6	0.1	1	0.6	7	1.1
Total		5 597	100.0	165	100.0	612	100.0

Source: Isett SETA (2002: 33–35)

APPENDIX D

ICT users, by occupational category

Table D1: The ISETT sector

Occupational category	Number	Percentage
Low level technology users	2 900	1.6
Administrative support	34 500	18.5
Electrical and electronic mechanics	10 500	5.6
Other technicians	7 300	3.9
Computing and associated professionals	18 200	9.8
Physical and engineering technicians	33 400	17.9
Business professionals	21 600	11.6
Engineers and related	15 300	8.2
Computing professionals	19 800	10.6
Managers and supervisors	22 900	12.3
Total	186 400	100.0

Source: AMI (2002: 15–16); Isett SETA (2002: 47)
Note: This table focuses only on those employees who use ICT in a way that is integral to their everyday work. For the purposes of this analysis it is assumed that R&D workers will work with ICT.

Table D2: The IT, telecoms and electronics subsectors

Occupational category	IT	%	Telecoms	%	Electronics	%
Low level technology users	2 200	1.9	300	0.5	400	2.7
Administrative support	18 300	15.6	12 200	22.5	4 000	27.0
Electrical and electronic mechanics	8 800	7.5	1 100	2.0	600	4.0
Other technicians	6 500	5.5	800	1.5	50	0.3
Computing and associated professionals	16 200	13.8	2 000	3.7	50	0.3
Physical and engineering technicians	9 500	8.1	21 600	39.9	2 300	15.5
Business professionals	14 500	12.4	4 800	8.9	2 300	15.5
Engineers and related	9 200	7.8	5 600	10.3	500	3.4
Computing professionals	17 700	15.1	1 100	2.0	1 000	6.7
Managers and supervisors	14 500	12.4	4 700	8.7	3 600	24.3
Total	117 400	100.0	54 200	100.0	14 800	100.0

Sources: AMI (2002: 15–20); Isett SETA (2002: 47–48)

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