HSRC RESEARCH OUTPUT
5794

Knowledge for development: the contribution of university-firm interaction in South Africa

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Report
March 2009

IDRC Project Number: 103470-009
IDRC Project Title: Knowledge for development: University-firm interactions in sub-Saharan Africa
Country/Region: South Africa, Nigeria and Uganda

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*This report is presented as received from project recipient(s). It has not been subjected to peer review or other review processes.

ABSTRACT

South Africa's task of catch-up is categorized as typical of a country attempting to traverse a 'middle' developmental phase, of creating conditions for firm selection and specialization to access global markets, to strengthen emergent networks and innovation activity - and simultaneously, to resolve historically determined lock-ins in human development, evident in high levels of unemployment, poverty and inequalities in education and health.

In this context, the demands on higher education are multiple, but the study focuses specifically on the demand for higher education to contribute to firm's technological upgrading and to increasingly effective selection and specialization.

Analysis of firm's interaction with universities to support their innovation and R&D activities revealed patterns of open innovation networks akin to those of catch-up and developed countries, particularly on the part of larger, more technologically intense firms with evidence of absorptive capacity. In these cases, universities are contributing to firm technological upgrading.

However, these tend to remain 'islands' of innovation, and innovation networks are not widely diffused across the economy to a large number of firms or entire industries. There is evidence of strong sectoral differences that require a great deal of further research: historical patterns of interaction between local universities and firms in mining and agriculture, inter- and intra- firm interaction both local and foreign firms in the financial and business services sector, and emerging new complex patterns in the manufacturing sector that require disaggregation by sub-sector and field to identify specific 'spots of interaction' that can be nurtured.

Case studies of university-firm interaction in health biotechnology, an emergent sub-sector targeted for public policy support, suggest that at this stage, it does not represent a 'spot of interaction' between universities and local health-related firms. The levels of scientific production within the higher education system are sufficiently strong to enable insertion into global scientific networks and to attract global firms, so that the higher education system is ahead of the local productive sector, which is still in its infancy with significant gaps in critical value chains. The analysis identified systemic failures in the institutions of the national system of innovation that constrain the development of capabilities that could support the emergence of a dynamic, competitive health biotechnology sub-sector.

Unreflective imitation of 'best practice' from universities in the United States and United Kingdom or Europe will not promote university-firm interaction that serves South Africa's task of traversing phase 2 to catch-up. Rather, a new national model of a *responsive university*, free from the negative baggage of the 'entrepreneurial' university and encompassing the core developmental tasks, can be elaborated as a more contextually appropriate, strategic alternative.

ACKNOWLEDGEMENTS

The firm data used in this report was based on the findings, reports and data from the National R&D Survey for 2005/06 and the South African Innovation Survey 2005. Both these surveys are undertaken by the Centre for Science, Technology and Innovation Indicators (CeSTII) of the HSRC. The author is grateful for the data and assistance supplied by CeSTII and in particular Julien Rumbelow, William Blankley and Cheryl Moses.

The report is based on a series of working reports produced by the South African country team – Glenda Kruss, Il-haam Petersen and Jo Lorentzen - and in that sense, is a collaborative effort.

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INTRODUCTION

Over the past two decades, there have been substantive shifts in the social compact between higher education and society. Unlike the centuries old tradition of the autonomous pursuit of knowledge and science, universities are now expected to be more accountable to society, the state and the market - in particular, more responsive to the demands of a global knowledge-based economy (Salmi 2007, Maassen 2006, Newman et al 2004, Audretsch and Phillips 2006, Jacob and Hellstrom 2000, Delanty 2000, Van Vught 2000, SAUVCA 2004). A decade ago, a world higher education declaration (1998) set out a key premise that has been influencing policy, research and university practice:

> Without adequate higher education and research institutions providing a critical mass of skilled and educated people, no country can ensure genuine endogenous and sustainable development and, in particular, developing countries and least developed countries cannot reduce the gap separating them from the industrially developed ones.

In the developed countries, one key focus of higher education policy and research has thus become the promotion of 'university-firm linkages'. A plethora of national incentive schemes, or new institutions such as science parks, or new organizational forms such as technology transfer offices and university-based spin-off companies or new policy frameworks to govern intellectual property rights and ownership have come to concern universities, giving rise to new managerial and organizational challenges, and new models of the university in its relationships with the state and the economy.

Our broad concern is with this changing role of higher education in relation to knowledge-based economic growth, innovation and development, for the countries of the South, which experience these new global imperatives under very different, often disadvantageous, conditions (Sagasti 2004).

Governments in developing countries are increasingly imitating developed countries, by adopting policy, incentives and programmes aimed to promote linkages between universities and firms. In Sub-Saharan Africa, with the largest share of low-income countries, there is evidence to suggest that policy-borrowing to promote university-industry linkages is occurring (Diyamett 2008, Kruss and Petersen 2009), but in a manner that does not take sufficient cognizance of the specifics of the local context and conditions, which may have unintended deleterious consequences (Altenburg 2008). There is as yet not a great deal of research on the changing role of universities, but what does exist often engages with the challenges in aspirational and normative ways (Etkowitz and Dsizah 2007, Adeoti 2002, Myamila and Diyamett 2006, Mwantimwa 2008). There has been little systematic analysis of the conditions of universities, firms and their potential for interaction to contribute to growth and development in the low income countries of sub-Saharan Africa.[1]

Such concerns inspired a study to examine systematically how university-firm interaction contributes to national development goals in three countries at different stages of development in sub-Saharan Africa, namely Nigeria, Uganda and South Africa. The

[1] See Muchie et al (2003) for a systematic attempt to interrogate applicability of the national systems of innovation approach in Africa.

study focused on differences in the extent of, incentives for and constraints on university-firm interaction in each of the three socio-economic and policy contexts.

This report presents the case of South Africa, a middle-income country atypical of, and an economic leader in, sub-Saharan Africa (World Bank 2007). It problematises the contribution universities make to national development goals through their growing emphasis on interaction with firms, in these conditions.

Our previous research on university-firm interaction in South Africa analysed the diverse ways in which different types of university are responding to and engaging with the global and local challenges, and developing strategies to link university-firm interaction with their institutional goals and mission (Kruss 2005 a, 2005 b, 2006). In particular, this work highlighted a tension between the financial and intellectual imperatives driving universities' interaction with firms, and the potential consequences of different ways of resolving this tension for individual universities and for the higher education system as a whole. The paper builds on this research, but does not focus on strategic issues at the institutional and organizational level.

Universities in South Africa have an established tradition of activity in relation to three missions, of social and community outreach alongside their primary roles of teaching and research. Over the past two decades, following global patterns, the outreach role has increasingly been redefined as a 'third mission' characterized by a range of forms of entrepreneurial and market-driven behaviour (establishing spin-off firms, university holding companies and science parks and the like). The paper will not focus on the extensive debate and research around this new 'entrepreneurial mission', and the set of complex issues concerning the new role of 'university-as-firm' or commercial entity.

Rather, the present project adopts a systemic lens, to investigate universities as critical institutions in the South African national system of innovation, and focuses specifically on their direct role in supporting technological upgrading and firm learning. This choice of focus does not imply that a normative or reductive argument, to promote a single, narrow role for universities as 'handmaidens' of the economy or of firms. On the contrary, the multiple roles of universities, and the significance of universities as knowledge generators for the long term health of a science and technology system and for a national system of innovation are fundamental assumptions for the research approach (Nelson 2004).

What the report proposes to do by way of analytical focus is to place firms at the fulcrum of investigation, to address a gap in our current understanding of university-firm interaction in South Africa (Kruss 2007, Lorentzen 2009). It will access an evolutionary economic literature emerging in relation to analysis of developing countries, framed in terms of national systems of innovation and 'catch-up' approaches, and foregrounding firm technological upgrading. Specifically, the paper adapts a framework developed by Sercovich and Teubal (2008) to analyse the challenges of dynamically traversing distinct phases in technological capability, innovation and competitiveness, in order to inform a systemic analysis of the contribution of university-firm interaction in South Africa.

In this manner, new insights may be injected into policy debate around higher education, innovation and sustainable development appropriate to South Africa, and in turn, inform debates about the challenges of global imperatives for universities in sub-Saharan Africa, and the South in general.

Section I of the report will briefly set out the conceptual framework and datasets on which the analysis is based. Section II demonstrates that South Africa as a middle income economy is traversing a specific phase of development, by benchmarking its innovative performance and providing an overview of the economic structure, policy framework and higher education system.

Section III problematises the contribution of universities to goals of economic growth through technological upgrading and diversification of firms' production activities in these conditions. The analysis is aggregated across the system and between specific industrial sectors, analyzing the extent and nature of firm demand for co-operation with universities in relation to their innovative and R&D practices. Section IV focuses on cases of university-firm interaction in health biotechnology, a sub-sector which South Africa has targeted as a priority, to explore the manifestation of contextually specific constraints and possibilities. The conclusion draws out implications for policy and for the changing role of the university in South Africa.

SECTION I. A FRAMEWORK FOR SYSTEMIC ANALYSIS OF UNIVERSITY-FIRM INTERACTION

A vast literature has emerged on the nature and impact of university-industry linkages as new organizational forms. In a systematic and comprehensive review, Klitkou et al (2007) have demonstrated that numerically, there is a predominance of research based on the experience of large, developed countries. Much of the research is empirically rather than theoretically driven, and in general, the levels of theoretical development in the field are underwhelming. A third distinctive feature of this literature is that in emphasis, it tends to focus on the university perspective and dynamics of interaction, rather than that of firms. Empirical research attention is typically paid to understanding the dynamics of a specific form of university-industry interaction, whether the extent of co-patenting or co-publication, the optimal conditions for promoting spin-off firms, technology transfer offices or science parks, and so on. There is also considerable focus in the higher education literature debating the merits and demerits of the related conception of the entrepreneurial university (Clark 1998, 2003, 2004, Etkowitz 2003, Douglass 2005, Cargill 2007) and the impact of new imperatives on the traditional contribution of universities to knowledge (Slaughter and Leslie 1997, Amaral and Magalhaes 2003, Dzisah 2007, Rip 2004, Harpur 2006, Tadmor 2006).

In counterpoint to this higher education-oriented literature, evolutionary economists have paid increasing attention to the central role of education and knowledge institutions to the ability of an economy to 'catch-up' or fall behind the leading economies (Nelson 2007b, Fagerberg and Verspagen 2007). Likewise, academic researchers are beginning to problematise the role of universities in economic 'catch-up' in developing countries (Mazzoleni 2008, Albuquerque 2001, World Bank 2008). A high level of R&D investment and high-level skills is widely hypothesized to explain the ability of some developing countries, typically newly industrializing countries such as South Korea, Taiwan and Malaysia, to succeed in 'catching-up' with leaders in the developed countries (Nelson 2007a, Abramovitz 1986).

While it has long been assumed that universities' contribution in developing countries is limited to their educational role, both academics and policy makers are now focusing on their potential role in technological upgrading in firms, to a more direct contribution to national industry and hence, competitiveness, growth and development (Schiller 2008). There is increasing research attention paid to the potential contribution of universities as knowledge producers interacting with firms to build learning and technological capabilities in a national system of innovation, and hence, contributing to sustained economic growth and structural change. The interest is in how knowledge institutions may be a source of innovation and change for firms in distinct sectors, and how the interaction among actors in networks plays a role in catch-up (Malerba and Nelson 2008).

A study by Cohen et al (2002) on the links between and impact of universities on firm R&D has been influential in stimulating empirical research in middle-income catch-up countries. Albuquerque et al (2006) have studied the significance of what they identify as 'spots of interaction' between universities and firms in Brazil which has an 'immature' national system of innovation. Arza and Lopez (2008) have compared the features of firms in Argentina that collaborate with universities and those that do not, in relation to their innovative performance. Intarakumnerd and Schiller (2008) investigate how universities can assist in adapting, upgrading and diffusing technology for firms in

Thailand in relation to local conditions. Such empirical research can contribute to extend our understanding of university-industry interaction in catch-up in developing countries.

A framework to analyse distinct phases of development

The theoretical challenge remains to identify specific conceptual tools that can explain the extent, intensity and performance of university-firm interaction in countries at different stages of development, with distinct sectoral compositions, in sub-Saharan Africa.

There are a number of possible ways to categorise national systems of innovation in countries at different stages of catch-up, with a fair degree of overlap in the delineation of groups of countries (Fagerberg and Srholec 2008, Bernardes and Albuquerque 2003). To illustrate by way of one example, Albuquerque (2001) identifies groups of countries in terms of the match or positive relationship between their levels of scientific development in key disciplines (as measured by ISI publications data) and the technological strengths that are significant sources for industrial development (as measured by USPTO patent data). The three groups that emerge are those 'catching up' (Korea, Taiwan), those mature national systems of innovation ahead of 'catching-up' (USA, Japan, Germany etc) and those immature national systems of innovation behind of 'catching up' (India, Brazil, South Africa). Catching-up countries are distinct in that they concentrate scientific resources for specific uses and display interaction between science and technology. Immature national systems of innovation tend to have less focus, on a wider range of unrelated disciplines, with only a few 'spots of interaction' between scientific disciplines and firms' technology needs (Rapini et al 2006).

This kind of categorisation (particularly a methodology reliant on patent and publications data) is difficult to adopt in sub-Saharan Africa, where threshold levels of income, scientific and industrial development may not have been reached, and key institutions – education, scientific, financial - may not be present (Altenburg 2008).

Hence, as one means to undertake this comparative task, we adapted a systems evolutionary framework for innovation and technological policy-making proposed by Sercovich and Teubal (2008). Their approach too, begins from the observation that while it is becoming widely recognized that 'knowledge-related variables' are vital to the attempt of developing countries to 'catch-up', few countries are succeeding. They attribute this largely to system failures in the development of innovative capabilities in the industrial sector and in the knowledge infrastructure, to overcome which require dynamic, integrated and differentiated policy approaches. Although their work focuses on competence building policies rather than university-firm interaction specifically, it is useful in its concern to illuminate the specific challenges developing countries face in terms of the interaction between firm innovation, knowledge systems and policy learning in the catch-up process, and in the possibilities it offers for comparative analysis (see also UNIDO 2005).

Based on a systems evolutionary perspective and building on the work of Imbs and Wacziarg (2003), they develop a framework to identify three trajectories of structural change and economic growth interacting with policy development. Their basic assumption is that key to economic development is diversification of sectoral production and employment, with sectoral specialization only occurring late in the development

process. This presupposes the ability to master a wide range of technological activities, but most developing countries are unable to develop policies to overcome the systemic constraints.

They propose that economies traverse three structural change-related phases as income per capita rises over time, each with different mixes of diversity generation and selection/reproduction/development events, leading to dynamic comparative advantages, manifest in new sectors and product classes that can successfully engage with global market conditions. As the transitions between phases proceed, the related productivity gains are increasingly diffused across the economy over time. The phases are shaped by the levels of development of each country's innovation system but at the same time, successfully traversing a phase will strengthen and develop the innovation system (see also UNIDO 2005).

'Phase 0' to 'Phase 3'

In order to traverse any phase, it is necessary to overcome low-level equilibrium traps that are present, which may not have been fully resolved prior to transitions to another phase, but can be consolidated in the later phase. Thus, a key feature of their approach that makes it suitable for the purposes of this study is that they propose a 'Phase 0' stage of development, characterized by a range of combinations of low-level equilibrium traps typical of many low income countries in sub-Saharan Africa. To shift from 'Phase 0' requires a transition in human development, in terms of addressing poverty, high birth rates, and meeting basic needs for education, health, environmental sustainability and political stability. In such conditions, there is little scope for the development of innovative capabilities, or for the promotion of university-industry interaction.

The main feature of 'Phase 1' is the generation of diversity, mainly in relation to firms rather than the industrial sector as a whole, and the beginnings of firm level selection, typically in small firms through experimental activities alongside traditional activities. It is of little use for countries in this phase of development to adopt policy frameworks imitative of the developed economies – including policies aimed to stimulate networks and interaction between firms and universities. Policies in this phase have a distinct purpose – they should be aimed at promoting innovation and experimentation, establishing a SET infrastructure and institutional base, and establishing framework conditions to overcome structural deficiencies and weaknesses and system failures.

'Phase 2' is characterized by the emergence of higher-level organizations, such as new industries, clusters and markets, and the balance tilts away from variation towards selection of products. Greater maturity and stability may be reached at the level of the individual firm but not at the level of a sector or cluster, the higher levels of organization. Policy goals in this phase should aim to create conditions for internalizing business innovation, enhancing networking and interactive learning and promoting a set of organizations able to take advantage of globalization. A focus on university-firm interaction thus becomes appropriate - and indeed critical – to traversing this phase.

Most countries remain stalled in this phase, with only a few having successfully made the transition to 'Phase 3' (the catch-up countries of Korea and Taiwan for example). Selection mediated by a policy-driven strategic thrust begins to prevail in Phase 3, targeting new industries, clusters and markets, which rely on a systematic allocation of resources to innovation processes that are viewed as a collective enterprise. Systemic

failures in relation to finance, skills, information and coordination are increasingly resolved, and interaction with knowledge institutions becomes more effective.

Ideal types
Such a framework appears fruitful for comparison of differences in the extent, intensity and performance of university-firm interaction across the three sub-Saharan African countries. The framework does not propose invariant phases of development in a deterministic process, but represents a set of dynamic ideal type phases that vary across countries, sectors and regions with distinct initial conditions. It also provides a means of comparison between South Africa and other countries of the South at similar phases of development such as Brazil, in terms of analysing universities' contribution to technological upgrading in relation to a distinct set of initial conditions and policy learning activities. It can provide a way of identifying systemic strengths and weaknesses, to inform interventions on the changing role of higher education.

Data sources

The report presents a synthesis of trends evident from the analysis of three data sources utilized in the study. It draws on three background reports that present a full treatment of the data, and can be consulted to complement the present synthetic analysis for greater depth and detail.

First, the report draws on a contextual analysis of higher education, innovation and development challenges in South Africa (Kruss 2008a), supported by analysis of key indicators of economic, educational, innovation and social performance in each of the three countries (Petersen 2008).

Second, an examination of firms' cooperative practices in general and with universities specifically, drawing on two data sources, in collaboration with colleagues from the Centre for Science, Technology and Innovation Indicators (CESTII) (Petersen and Kruss 2009):

A. The South African Innovation Survey 2005, based on the Oslo Manual, measured firms' innovation-related activities for the period 2002 to 2004. A total of 981 responses from a random stratified sample of 2 627 companies was garnered, and of these, 603 firms that responded to a question on co-operation were included in our dataset for further analysis on their cooperative practices – that is, a sample of innovative firms with cooperative practices (see DST 2008).

B. The South African R&D survey 2005/06, based on the Frascati Manual, obtained responses from 607 firms, of which 327 responded to a question on firm collaboration, forming a sample of R&D performing firms with cooperative practices for our analysis (See CESTI 2007).

Third, nine case studies were conducted in two very different universities, focusing on the form, intensity and performance of interaction with firms in one key sector targeted by policy, the health biotechnology sub-sector (Kruss 2008b).

SECTION II. SOUTH AFRICA – TRAVERSING PHASE 2

Since 1994, with the transition to a democratic government in South Africa, there have been dramatic changes in governance, in the economy, in science and technology policy and in higher education. Unlike many other countries where change has been more gradual or piecemeal, the political transition was an opportunity for rupture of the fragmented system of the past, towards a systematic attempt on the part of the new state to put in place new policy, structures and mechanisms to promote growth and development to meet democratic goals in a globalising economy. The challenges of effecting structural change of course, are formidable.

Benchmarking South Africa's innovation performance

South Africa is the largest economy in Africa (Kasekende et al. 2007) and the most industrialized country in the sub-Saharan African region (Pietrobelli 2001). In 2006, South Africa accounted for 22.7% of the total nominal GDP for Africa and 34.5% of sub-Saharan Africa.

However, the assessments of a number of global benchmarking systems tell a consistent story that leads one to categorise progress and current levels of development as typical of a country grappling with the challenges of traversing 'Phase 2':

- UNIDO's Competitive Industrial Performance Index[2] places South Africa as part of a cluster of countries (along with Brazil, China, India and Saudi Arabia) with medium to low manufacturing value-added per capita, although it leads in sub-Saharan Africa.

- South Africa is classified as a 'dynamic adaptor' in the UNDP's Technological Achievement Index[3] (UNDP 2002), again in the company of developing countries like China, India and Brazil that are dynamic in using new technology, have significantly higher human skills than 'marginalized' countries, are likely to have some high technology industries and technology hubs, but have slow diffusion of old innovations.

- South Africa and Mauritius are the only sub-Saharan African countries classified as having 'medium' innovative capabilities using UNCTAD's Innovation Capability Index [4].

- The World Bank's Knowledge Assessment Methodology (KAM)[5] categorised South Africa as a middle income country, and its performance on the knowledge

[2] The index assesses a country's ability to produce manufactures competitively.
[3] Although the Technology Achievement index is now somewhat dated, it provides a useful classification of countries at different stages of development with regard to disparities, diversity and dynamism in technological achievement (Utz 2006).
[4] UNCTAD's Innovation Capability Index (UNICI), elaborated in its World Investment Report 2005 uses proxies to assess innovative activity (the Technological Activity Index) and the availability of skills for such activity.

economy index is lower but similar to the world average. Its performance is considerably lower than the average for upper middle-income countries, and its performance appears to have declined[6], indicating that the country is not keeping pace with the rest of the world and the relevant income region.

In general, South Africa tends to lead in Sub-Saharan Africa, it tends to be classified as a middle income country in the company of Brazil, China and India, amongst others, and it scores close to or just below world averages, but it is not among the leading developed nations.

Two further features are marked: South Africa's scores typically reflect an unevenness within its capabilities; and for those indices with a longitudinal dimension, over the decade of the 1990s, South Africa generally slipped downwards in the rankings, suggesting that peer countries were developing capabilities at a faster rate.

Taken together, these trends suggest that the country has a great deal of innovation potential but may not be succeeding in 'keeping up' with the pace of global development (Petersen 2008). This is typical of an observed 'Red Queen' effect (Ribeiro et al 2006, Bernardes and Albuquerque 2003), in which catch-up countries need to exert extensive effort merely to ensure that they do not fall further behind.

The following sections provide a broad overview of the South African economy, highlighting the long history of structural inequality that places major constraints on attempts to traverse 'phase 2', for 'keeping up' and for 'catching-up'.

The South African economy: a broad overview

Hirsch (2005) analysed the intense macro-economic policy debates and the shifts in economic policy after 1994 to pursue a dual agenda of growth and redistribution, providing a useful overview of the structure of the economy and its growth prospects. The trend towards diversification and selection is evident, but so too are the effects of significant unresolved transitions in human development.

A sectoral overview

By the 1990s, the traditional strength of gold mining in the economy had weakened due to shifts in world production and to the fact that South African mines depended more on cheap labour than innovative extraction, although there was growth in other metals and minerals such as platinum and coal in the 1980s (Hirsch 2005). Agricultural exports too, declined dramatically over the past decades, given the lack of arable land coupled with historical patterns of land ownership and the distance from global markets, which constrain development, although there are opportunities for expanding high-value products. The services sector had grown dramatically - and Hirsch argues that the potential of this sector for growth in relation to exports and employment was

[5] The Knowledge Assessment Methodology (KAM) was developed by the World Bank Institute's Knowledge for Development Program in 1999. The KAM was designed as an interactive Internet-based tool for benchmarking countries' and regions' overall level of development in the knowledge economy.

[6] While, on average, upper middle-income countries improved somewhat since 1995, South Africa appears below the 45-degree line indicating that its recent KEI performance (around 2000) declined relative to its performance in 1995.

underestimated in policy formulation processes in the 1990s. Instead, influenced by international debates, new policy targeted growth in the manufacturing sector as the most promising, particularly, expanding the scale and range of exports.

A broad sectoral breakdown of the South African economy in 2005 shows that the economy is now relatively diverse in structure (Figure 1). In 2005, finance and business services (21.4%) and manufacturing (18.6%) each accounted for about a fifth of GDP. The third and fourth largest sectors are government services, and wholesale and retail trade, restaurants and hotels. Primary commodities, agriculture (2.7%) and mining (7.3%), contributed considerably less to GDP.

Over the past few decades, there has been a strong shift towards the services sector such that taken together, the services sector in total contributed 69.2% to GDP in 2005, while industry contributed 27.9% (Table 1). The fastest growing sub-sectors are financial and business services, and transport, storage and communication.

Employment is largest in the services sector, with 26.5% of total employment in the personal social and community services sector, and 26.1% in the trade, catering and accommodation sector (and 43% of informal employment) in 2005 (OECD 2007). This has led some analysts to conclude that given its historical trajectory of development as a dual economy, South Africa is undergoing a kind of 'de-industrialisation' process that is not typical of its level as a middle income country (Rodrik 2006, OECD 2007).

A limited diversification of exports

Contributing to this interpretation is the fact that South Africa's trade structure is similar to that of the world and middle income countries. Notably, the country's agricultural sector (as a share of GDP) is much smaller than that in Africa as a whole and the sub-Saharan African sub-region, and the share of the services sector is much larger.

As the analysis of benchmarking indices above suggests, South Africa's ability to catch-up with other middle income countries is constrained. The OECD (2007: 27) indicates that even though South Africa's economy has become more diversified in recent years, global exports continue 'to be dominated by "mineral-based" items', such as mining, basic iron and steel. There has been a late diversification of exports in the 1990s, indicating comparative advantage in textile-related products, pulp and paper, petroleum products, vegetables and fruits for example, but there are questions as to whether these are sufficient to sustain growth. Advancing the diversification of exports is still identified as a key challenge (Presidency 2008, Edwards and Lawrence 2006). Technological upgrading – and hence, interaction with knowledge producers, including but not limited to universities - is critical for diversification of exports.

The expected FDI inflows after 1994 have not materialized to any significant extent (and indeed, the current recessionary conditions in 2009 make this an even more significant constraint). Investments tend to be short term and FDI in general is low relative to other middle income developing countries (Presidency 2008). FDI is believed to be constrained by skills shortages and lack of infrastructural development, which may act to limit growth of a national system of innovation.

Kaplan (2008: 7) argues that technological progress, as measured by total factor productivity (TFP) growth, is important for economic growth in South Africa, but has not

been sufficiently recognized in economic policy. He notes that TFP increased over the 1990s but has slowed down recently, which needs to be addressed in order to contribute to long term economic growth.

Unresolved issues of human development a structural deficiency

Clearly, we may categorise South Africa as an economy traversing Phase 2, and attempting to shift to Phase 3. Its structural deficiencies, systemic weaknesses and potential failures relate to its nature as a dual economy, to the as yet unresolved problems of human development, poverty and inequality. South Africa remains characterised by the structural inequalities of an economic and social divide that evolved since the period of colonial conquest in the seventeenth century, systematized in the apartheid era in terms of a racially defined division of labour, and reinforced through the unequal and segregated provision of education, health, justice, social services along racial and ethnic lines[7]. Critical issues are the persistence of structural unemployment (Banerjee et al 2006 Bhorat 2004, PCAS 2003, and Altman 2005) and the extent of social redistribution of the benefits of economic growth. The highly unequal concentration of income leads to limited demand in home markets, and hence, may act as a constraint on technological progress (Albuquerque 2007).

Some of the low equilibrium traps typical of sub-Saharan countries are thus to be found in some (particularly, but not solely, rural) regions within South Africa. High levels of poverty, unemployment and exclusion from education and health benefits co-exist with growing opportunity and wealth. The GINI coefficient has increased over the past ten years, to 0.685 in 2007. The population total stands at 47.9 million in mid-2007, 79.7% of whom are classified as African, 9.1% as White, 8.8% as Coloured, and 2.1% as Indian/Asian (Statistics SA 2007). The distribution of richest and poorest remains defined along these racial lines, but there is also evidence to suggest that there is widening inequality within race groups and a decline of inequality between race groups, reflecting the growth of the middle classes (Presidency 2007: 24).

Innovation is thus inextricably bound up with addressing the human development issues (health, housing, education, nutrition) required as a necessary enabling condition for economic shifts. The potential for (parts of) the South African national system of innovation to compete in the global knowledge economy is evident (NACI 2006, OECD 2007), but human development demands operate as a potential binding constraint and require critical efforts to ensure change.

A policy framework centred on promoting a national system of innovation

A strategic priority for countries traversing Phase 2 is accelerating innovation, evident in the promotion of innovation and R&D capabilities in the business sector, particularly in cooperation with institutions of science, engineering and technology. South Africa has elaborated policy goals appropriate to a country traversing phase 2.

[7] See Gelb 2003 for detailed historical and contemporary analysis of the causes and nature of inequality in South Africa.

The innovation challenges are reflected in a dualism in national policy goals – aimed at meeting human developmental needs and addressing poverty, at the same time as achieving competitiveness and technological advancement in a globalizing knowledge economy.[8] An ambitious, comprehensive science and technology policy framework was elaborated, which aims explicitly to promote the transition from a resource to a knowledge-based economy (DACST 1996, DST 2002, DST 2007). The framework has clear direction, embodies a formal commitment to coordination across relevant government departments, and initiates a set of funding incentives and strategic mechanisms and programmes. The explicitly stated policy goals and 'national system of innovation' framework[9] have drawn heavily from and are imitative of, the cutting edge of theory and practice in developed economies. The policy framework aims to bring about structural change in the existing patterns of linkages and interactions between institutions, sectors and firms. One successful example is a funding mechanism that has provided matching-funding as incentives to promote research collaboration on research and graduate training between universities, public research institutes and firms (THRIP[10]). Other examples are programmes to promote innovative research that can lead to commercialization, such as the Innovation Fund (HSRC 2003), or the establishment of incubators and science parks, or programmes to enhance technology transfer and upgrading of SMMEs. Formal policy thus reflects the aspiration to catch-up in productivity and income to levels typical of Phase 3, and in practice has tended to prioritize technological upgrading to promote comparative advantage and global competitiveness, while paying lip service to technology for poverty reduction.

The promotion of innovation and R&D capabilities

The new policy framework has led to a degree of progress, measured in terms of the levels of firm innovation and R&D performance.

South Africa reported gross domestic expenditure on R&D (GERD) of R14 billion in 2005/6, which represents 0.92% of GDP, close to the target set to attain 1% by 2008 (DST 2007), and a steady increase from 0.76% reported in 2001/2[11] (DST 2004). This is low relative to developed economies but similar to other middle income economies such as Brazil. Notably, the R&D survey 2005/6 covered a small total number of 607 firms. What is unusual for a country in South Africa's phase of development is that business enterprises were responsible for 58.3% of the total expenditure, followed by higher education (19.3%), science councils (14.9%), government (6%) and not-for-profit organizations (1.6%) (CeSTII 2007).

Likewise, in the three-year period 2002 to 2004, a comparatively high 51.7% of South African firms reported that they were engaged in innovation activities, with a total

[8] These goals have received differing emphasis in specific strategic policies, incentives and steering mechanisms, and differ in terms of the degree of effective implementation and delivery, over the past fifteen years.

[9] The national system of innovation is defined as 'the means through which a country seeks to create, acquire, diffuse and put into practice new knowledge that will help that country and its people achieve their individual and collective goals' (DACST 1996: 15).

[10] Technology and Human Resources for Industry Programme initiated by the Department of Trade and Industry. For an analysis of the beneficiaries and outcomes of the programme, see HSRC 2003.

[11] This was the first year when the survey began to follow the Frascati Manual Guidelines under the new Ministry of Science and Technology.

expenditure of R28 billion, representing 3.2% of their turnover (DST 2008). These levels compared favourably when benchmarked on many indicators with EU-27 states, particularly the transition countries of Eastern Europe and new accession states (DST 2008). The main type of innovative activity engaged in tends to be the acquisition of machinery, equipment and software, 54.1% of innovative firms, which accounts for the largest proportion of innovation expenditure. Intramural R&D is an activity for 51.7% of innovative firms, while 28.3% of innovative firms were engaged in the acquisition of other external knowledge such as the purchase or licensing of patents, and only 19.3% engaged in extramural or outsourced R&D.

Higher education expansion, diversity and flexibility in South Africa

A key strategic priority and action area for traversing Phase 2 is to intensify the focus of universities on addressing firm demand, in general and in relation to selected sectors and technologies. In South Africa, there is an expressed policy commitment to enhance the responsiveness of the higher education system, both economically but also in terms of general social responsiveness to widen access and address inequality (CHE 2004, SAUVCA 2002, and Favish 2003). However, there are indications of weaknesses in the higher education system that need to be addressed, typical of a country traversing Phase 2, but strongly shaped by unresolved low-equilibrium traps in education.

Expanding the higher education system
A rapid acceleration of global standards of educational achievement as occurred over the past two decades (Brundenuis et al 2008), an exponential expansion to create mass higher education systems (Mazzoleni 2008), which serves to widen the gap for transition from Phase 2. This poses challenges to South African universities in terms of their core role of teaching, to produce more graduates with more of the kinds of qualifications and skills required by firms, particularly those in priority selected sectors at this phase of development.

Table 2 reflects the total enrolment of the higher education system over the past decade, showing a period of decline after 1994 related partially to funding constraints, followed by rapid growth from 2001, and then a slow annual growth to a system with around 750 000 enrolments (See Cloete et al 2002, OECD 2008 for further analysis). The system is growing, but the participation rate is low relative to countries at similar levels of development, currently around 15%. The data also reflects the slow progress with respect to the policy-driven attempt to shift the balance of enrolments to be more responsive (DoE 2001, Moja and Hayward 2000), away from education, the social sciences and humanities and towards science, engineering and technology, as well as business studies (CHE 2004).

A major system weakness in South Africa relates to unresolved inefficiencies and inequalities in the schooling system that limits access, throughput and further growth of the higher education system. There is not a large enough pool of school-leavers with the required certification to enter higher education, particularly in the critical fields of science and mathematics, in order to grow science, engineering and design fields (Reddy 2006). Human resources and skills development are receiving increasing policy priority, but the low-level equilibrium lock-in in the schooling system has yet to be resolved (Fiske and Ladd 2004)

Higher education is directly affected further, in terms of quality and throughput, as universities grapple with the consequences of expanding access rapidly in line with equity goals, with large numbers of under-prepared students (Luescher and Symes 2003). Table 3 reflects the low level of graduations and outputs from the higher education system, and that graduations are more focused in the humanities, social sciences and education than are enrolments. Over the past few years the national department of education has imposed a cap on growth in enrolments in order to focus on the quality of the system, motivated by the systemic inefficiencies reflected in high drop-out and low graduation rates across many institutions (see Steyn and De Villiers 2006 for an analysis of this strategy).

An expansion of the higher education system is thus required for transition to Phase 3, particularly in relation to producing research capable graduates, but a recent OECD (2007) review reiterated the concern that it may not be possible to sustain current levels of R&D in universities, let alone expand the system significantly (Koen 2006, 2007, COHORT 2004, Kahn et al 2006).

Diversity and flexibility of the system

However, Mazzoleni (2008) draws from comparative historical analysis to argue that a rapid quantitative expansion is not always accompanied by qualitative changes in terms of a match of skills and graduates with firm demand and employment opportunity. He cautions against 'over-blown expectations' of the developmental possibilities inherent in an expansion of national enrolments in higher education, as a return on the investment is only likely in the long term and will not immediately lead to the accumulation of technological capabilities. He instead proposes that institutional diversity and flexibility are key.

South Africa has a historically differentiated higher education system (Cloete et al 2002, Kahn et al 2007) which is potentially positive. Unfortunately, there has been a high degree of segmentation between historically-defined types of university, which militates against flexibility and change across the system. A high degree of segmentation between organizations in the national higher education system can discourage researchers from undertaking a wide variety of research and from moving between different types of university, without loss of reputation (Whitley 2003). This lack of flexibility and articulation can slow down the rate of knowledge and skills transfer and diffusion across the higher education system.

A recent restructuring process has created three new institutional types – universities, comprehensive universities and universities of technology – that aim to provide a more diverse mix of academic, research, technological and occupational focused institutions in the system (Ministry of Education 2002, CHE 2004). This policy-driven change may serve to shift the tendency to segmentation, and promote greater differentiation, openness, flexibility and exchange. It is also likely that more specifically targeted incentive mechanisms are required to promote collaboration and networks across the higher education system, to support both quantitative and qualitative growth, wider access and improved economic and social responsiveness.

Traversing phase 2

South Africa may be characterized as traversing Phase 2, with evidence of sectoral diversification and some evidence of specialization emerging, but an inherited highly unequal concentration of income and opportunity. There is a degree of maturing of the institutions of the system of innovation, but significant system weaknesses arising from unresolved human development low-level equilibria. In particular, constraints in relation to education and human resource capabilities lead to fragility in the emerging national system of innovation.

The following section analyses the extent and intensity of university-firm interaction in these systemic conditions, drawing on innovation survey and R&D data to illuminate South African universities' direct role in technological upgrading in firms.

SECTION III. UNIVERSITIES CONTRIBUTION TO FIRMS' INNOVATION AND R&D ACTIVITIES[12]

In developed economies, with the increase in knowledge-intensity of innovation, availability of venture capital, greater mobility of knowledge workers and a reduction in product lifecycles, innovating has become a very expensive and risky activity that makes co-operation essential for competitiveness. No longer is a firm's internal R&D facility on its own its main strategic asset. Innovation is increasingly a networked activity, and a firm's ability to organize and manage the innovation process - including strategic partnerships and sourcing knowledge and discoveries (such as licenses or patents) from elsewhere or outsourcing R&D - is seen as imperative for its competitiveness (Chesbrough and Crowther 2006). University-firm interactions in developed economies, mainly Europe and the United States, have been characterized as increasingly displaying such features, a model of 'open innovation systems' (Chesbrough, Chesbrough and Crowther 2006, Gassmann 2006, Lichtenthaler and Ernst 2006, van de Vrande et al. 2008).

It is likely that the university-firm interactions emerging in South Africa would reflect the strategic priorities and systemic weaknesses typical of a country traversing Phase 2, and aspire to develop such open innovation systems. Typically in phase 2, one may expect to find 'islands' of innovation activity, with cooperative interaction between cutting edge firms and with the emerging science and technology system. As Rapini et al (2006) have proposed in Brazil, there are a limited number of 'spots of interaction' where local university research strengths in specific science and technology fields match firms' technological specializations and needs. They speculate that such 'spots of interaction' typify the nature of interaction in immature national systems of innovation.

One may also expect to find that a larger number of firms use innovation-related design and engineering capabilities to enhance competitiveness to enter competitive domestic and global markets (Sercovich and Teubal 2008). The source of such innovative product selection and development is often user/supplier relationships, rather than universities or other scientific institutes. Experimental activities by small non-R&D performing firms may take new forms, for example, as high technology spin-offs. Groups of firms that may later form the basis for a new industry would typically begin to appear in a small number of sectors, as do the conditions required for their emergence, particularly interaction with universities.

This section will show that given the dual nature of South Africa's economy, there is evidence of a set of technologically sophisticated firms interacting in open innovation networks, including with universities, akin to the trend in developed economies. However, these represent 'islands of innovation' in relation to the total landscape of firms, and activity is stronger in relation to technological exploration but virtually absent for technology exploitation. Some of the potential 'spots of interaction' are then examined by means of a sectoral analysis of firm's cooperation with universities on their innovation and R&D activities.

[12] This section draws strongly on the background report prepared by Petersen and Kruss (2008) with data support from colleagues at CESTII.

Firms propensity to cooperate on innovation and R&D activities in South Africa

The research literature on open innovation networks in Europe and America suggests that firm size, technological intensity and degree of insertion into global networks are associated with the propensity of firms to use open innovation practices, and cooperation with universities in particular (Laursen and Salter 2004, Cohen et al. 2002, Fontana et al. 2006, Tether 2002).

Analysis of South African Innovation Survey data suggests that local innovating firms that co-operate on their innovation activities with any partner - whether other firms, universities or research institutions - similarly tend to be larger in size (in terms of employee numbers), have a higher turnover, a higher innovation expenditure (particularly on intra-mural R&D) and a higher level of knowledge intensity in personnel (contributing to absorptive capacity) than those firms that do not cooperate at all (Table 4 and 5). Large firms thus appear to co-operate to seek complementary capacity for their innovation activity, rather than to substitute for lack of capacity.

The trends in relation to R&D performing firms are similar but more marked. Firms that cooperate in general are larger in size, spend significantly more on R&D, with a far higher research complement and report less basic and experimental research than the firms that do not cooperate (Table 6 and 7). These trends likewise suggest that firms seek to cooperate to complement internal R&D capability.

Firms propensity to cooperate with universities specifically

Firms' propensity to cooperate with universities specifically follows a similar pattern. Analysis in this section compares three groups of firms – those that cooperate with universities (which may be in addition to other partners), those that cooperate with other partners but not with universities, and those that do not cooperate on their innovative and R&D activities at all.

Cooperation with universities for technology exploration

Drawing on the Innovation Survey data, of 264 innovating firms that co-operate on their innovation activities, 108 reported that they partner with South African universities. Only two of the firms that collaborate with foreign higher education institutions do not also collaborate with local higher education institutions.

There are 120 R&D performing firms that cooperate with local universities (the largest group of cooperative partners), and 98 firms that cooperate, but not with local universities.

Innovating firms with higher employee numbers and greater turnover – the larger firms – show a greater propensity to co-operate with local universities (Figure 2). Innovating firms that cooperate with universities spend twice as much on their R&D than the non-university cooperators, and four times more than the firms that do not cooperate at all (Figure 3). This expenditure may be concentrated in a few large 'big spender' firms, as when we consider the frequency of firms, in relative terms, fewer university cooperators conduct in-house R&D, suggesting that there is also a group of firms that seek partnerships with universities to substitute for their own intra-mural R&D capacity.

While the firms that cooperate with universities have higher innovation related expenditure overall, they show lower innovation intensity than the non-university cooperators. This may be related to the large proportion of expenditure on the acquisition of machinery, equipment and software (47% of the university-cooperators' expenditure and 65% of the non-university-cooperators' expenditure).

The propensity to cooperate with universities on innovative activities also appears to be stronger for firms with higher levels of technological intensity (that is, a larger highly-skilled workforce and those with higher levels of R&D intensity). A higher frequency of these firms engage in the more knowledge intense innovation activities, and tend to rely more on external sources for their R&D to complement their internal R&D activities. It may also be that they rely on external sources to substitute, as in the case of the 21.3% of the university-cooperators that do not conduct intra-mural R&D.

The university-cooperators and non-university cooperators interact with a range of different partners on their innovation and R&D activities, and analysis shows distinct networking patterns.

Market-related resources - particularly their clients or customers, suppliers and other firms – are most important for the non-university-cooperators (Figure 4). Public research institutions are least important to them. This is in stark contrast to the cooperative tendencies of the university-cooperators, for whom consultants, commercial laboratories or private R&D institutes are as important as the firms' clients or customers; and government or public research institutes are as important as the firms' suppliers. More of these university-cooperators also cooperate with other firms, including their competitors.

Thus, the firms that cooperate with local universities on their innovation activities show a propensity to co-operate with knowledge institutions and rate knowledge intensive sources of information more highly than firms that co-operate with other kinds of institutions. The non-university cooperators typically may be firms that use innovation-related design and engineering capabilities to enhance competitiveness, for which suppliers and users are the most important sources of selection.

Insertion in global networks

The non-university cooperators however, tend to connect more in global networks than the university-cooperators, with foreign partners outside of South Africa. In general, the innovations reported by firms originated mainly in South Africa. The larger proportion of the non-university cooperators' report innovations originating abroad, followed by the group of firms that do not co-operate on their innovation activities at all. The university-cooperators are less likely to report innovations that originated abroad, suggesting that for this group of firms, local universities play a key role.

Analysis of the R&D Survey data shows similar trends, with the non-university cooperators preferring to cooperate with firms, but these firms do not show propensity to seek knowledge institutions abroad. The R&D firms cooperating with local universities show similar tendencies to the firms in the innovating sample when seeking partners abroad.

There is a small group of 31 R&D performing firms that cooperate with foreign universities, and this group shows a propensity to cooperate with foreign partners generally, concentrated in two sectors – mining and agriculture. The 31 firms represents

a specific group of 'big spenders' on R&D, representing 14% of the cooperating sample but 21% of the total R&D expenditure, and accounting for more than a third of the total spent by firms cooperating with universities (locally and abroad). The high level of these 31 firms' R&D activity and cooperation activity generally implies that firms are more likely to engage international higher education institutions once a certain level of R&D expenditure is reached, and also when co-operation frequency with other partners is already high. Here are clear of 'islands' of innovative activity – and they are inserted into global networks.

Outcomes of cooperation with universities

The university-cooperators report considerably larger proportions of total turnover that comes from innovating goods and services new to the market or new to the firm than the non-university collaborators and the firms that do not co-operate at all.

The level of firm exploitation of new discoveries is generally very low in South Africa, and collaboration with universities does not appear to offer any significant advantage (Figure 5). Less than 10% of all firms in the total sample were awarded patents in South Africa in the period 2002 to 2004, 6.4% applied for patents abroad, 5.4% registered industrial designs, 19.5% registered trademarks, 7.6% claimed copyrights, and only 3.6% received license grants.

For the total sample, product outcomes are of high importance for most firms, in rank order: improved quality of goods or services (42.9% of firms), increased range of goods and services (39.4%) and the ability to enter new markets (34.9%). The firms that co-operate on their innovation activities, particularly those that report co-operation with local universities, share these perceptions, but more firms rate them as highly important (Figure 6). The university-cooperators reported slightly higher levels of success in entering new markets or increasing their share in the market and higher levels of success in improving the quality of their goods or services.

Across all sectors, the firms reported that, on average, the most successful process outcome was increased capacity for production or service production. The university-cooperators generally reported average levels of success on process outcomes higher than the non-university cooperators, and the most distinctive difference between the groups is the importance of reduced environmental impact or improved health and safety, and the meeting of governmental regulatory requirements.

Firms propensity to co-operate with local universities may be influenced by their assessment of the obstacles to innovation (Figure 7). On average, the greatest obstacle to innovation reported by firms is a lack of qualified personnel. The university-cooperating firms rate other knowledge related obstacles as slightly more significant in hampering their innovation activities than the non-university cooperators. Cost factors, namely lack of funds within the enterprise or group, are also highly significant. Of note, as a group, the firms that do not cooperate with universities identify a distinct set of obstacles to innovation, rating lack of funds within the firm and lack of qualified personnel as the most important obstacles, followed by a lack of finance from outside sources, and market saturation. The fact that these firms do not seek complementary networks with universities suggests an area of latent potential that requires further exploration.

Islands of open innovation networks

The analysis suggests that universities are playing a role in open innovation networks to support technological upgrading and firm learning in South Africa – at least, for some firms. The proportion of firms that cooperate with universities on their innovation, 15% across the system, is comparable with that of many developed economies, with the EU-27 average standing at 8.8% (DST 2008). Firms' propensity to draw on local universities as co-operation partners is associated with larger firms and higher levels of technological intensity, and more with high-technology industries. More important, firms' propensity to co-operate with universities appears to be associated with higher levels of open innovation practices in general, that is, of cooperation networks with other firms, suppliers and customers or external knowledge actors.

This is an encouraging trend in terms of the potential contribution of universities to firm technological upgrading, and the prospects of catch-up in South Africa.

The diffusion of such open innovative practices across the national system of innovation is critical for traversing Phase 2, and here, the trends in relation to the total number of firms involved, to the scale of interaction, and the spread across sectors, particularly emergent sectors in which South Africa may develop competitive advantage, are not as encouraging.

The scale of co-operation on innovative and R&D activity in terms of the absolute number of firms involved is very small, particularly in comparative terms with catch up countries or developed OECD countries (Table 8).[13] The propensity of small and medium firms to cooperate with universities is quite limited, and there are strong sectoral differences in the propensity to use open innovation practices.

Firms that cooperate on innovation are more likely to be in the manufacturing sector (50.4%), followed by wholesale and retail (20.5%), financial and business services (13.6%) and few in the mining sector (4.2%) (Table 8). Sectoral differences are evident in the types of innovation expenditure of cooperating firms. Mining firms tend to outsource R&D, while financial and business services firms tend to conduct their R&D in-house to support their innovation activities, and the wholesale and retail services reported the lowest levels of R&D intensity and innovation intensity.

Similarly, cooperating R&D firms are concentrated in the manufacturing sectors, with 92% of firms in high-technology sub-sectors reporting collaboration. Half of the R&D performing firms in financial and business services cooperate, and few wholesale and retail firms are included in the sample. Striking is that although there is a small number of firms in the traditionally strong resource-based mining and agriculture sectors, 100% report cooperation on their R&D activities (Table 8).

Innovating firms in industry – the manufacturing and mining sectors - show a higher propensity to co-operate with universities specifically than do those in the services sector – financial and business and wholesale and retail sectors - and may rely more on universities for successful operation. Higher R&D intensity and innovation intensity are

[13] We do not know if there is any overlap between these datasets. Moreover, these numbers are not weighted to the total population of firms in South Africa.

associated with higher levels of interaction with universities for industry, particularly mining firms. The analysis suggests that the wholesale and retail sector relies more on external sources – although on universities to a lesser extent – for their R&D and innovation needs. The financial and business sector firms that cooperate with universities have lower levels of R&D and innovation intensity than the non-university cooperators, suggesting that firms in the sector tend to rely on in-house capacity for their innovation needs, and prefer partners other than universities.

The university-cooperators in sectors other than manufacturing reported a smaller proportion of goods and services that were unchanged or only marginally changed, in comparison to the non-university cooperators. This suggests that for the mining and services sector firms, co-operation with local universities is associated with higher innovation capability.

The small absolute number of firms and the uneven sectoral spread of interaction between firms and the knowledge subsystem suggest that the innovating and R&D performing firms that cooperate with universities represent the cutting edge of what is possible, the 'islands' of firm activity typical of countries traversing phase 2. The following section describes trends in university cooperation in key sectors in the South African economy, of necessity working at a high level of sectoral aggregation, pointing to potential 'spots of interaction'.

Spots of interaction: sectoral interaction and potential

The manufacturing sector: local and global networks

In advanced economies, university-industry interaction is found most commonly in relation to the manufacturing sector, to contribute technological intensity to manufactured exports – a pattern that is found in South Africa as well, in relative terms. More manufacturing sector firms innovate, and collaborate, and collaborate with local higher education, than firms in the other sectors, which is a positive pattern.

Nevertheless, the scale of activity in absolute terms is very small. A total of 367 innovating firms were surveyed in the manufacturing sector, a high 50% of whom collaborate, 16% with universities and 4.5% of whom reported that universities are highly important sources of information (Table 8). In real terms, this means a small group of firms[14] interacting with universities – and it is the highest proportion and the greatest total number of all the sectors.

The group of university-cooperators accounts for the lions' share, 79%, of the manufacturing sectors' total innovation expenditure, with most of the expenditure dedicated to in-house R&D (see also Figure 1 for the university-cooperators share of sectoral turnover). Analysis of types and outcomes of innovation suggest that cooperating manufacturing firms are more at the 'cutting edge' than non-cooperating firms, and that cooperation with local higher education seems to contribute to some extent. The evidence suggests a concentration of knowledge intensive innovation activity in cooperation with universities in only a small group of firms.

[14] 59 firms in the innovation sample unweighted.

A similar pattern is found in relation to R&D performing firms, although here, a larger proportion of the manufacturing firms – particularly high technology firms - cooperate with universities, and the total number of firms is very slightly larger. Here too, the firms that cooperate with universities account for total R&D expenditure almost double that of the non-university cooperators, and almost 10 times that of the firms that do not cooperate at all. Again, this suggests a concentration of activity amongst a small group of firms.

Innovation at the frontier accounts for around 13% of the innovation turnover of firms in this sector whether these firms co-operate with local higher education or not. Innovations that were new to the manufacturing firms that co-operate with local universities accounted for a smaller proportion (13.6%) than for the non-university cooperators (18.5%) and for the manufacturing firms that do not co-operate at all (17.7%). These trends suggest that innovation activity within this sector may be more complex than the other sectors.

Interpreting the data is made more complex by the broad aggregation of a 'manufacturing' sector, with a wide range at least 17 sub-sectors, with the largest sub-sectors being food and beverages, chemicals, defence, pharmaceuticals, and electronics, in rank order (Table 9). A wide array of research fields are involved in cooperative R&D, most commonly engineering, and applied sciences and technology, although there is activity in a range of fields including material science, agricultural, medical and health, chemical sciences and ICT. The possibilities of emergent sectoral innovation systems, particularly in the high technology sectors may be present, but it is evident, far more sub-sectoral research is required to pursue the implications and potential impact of the trends identified.

A traditionally knowledge-intense sector: university interaction in the mining sector
The mining industry is traditionally knowledge intense and has a long entwined history with universities. Cooperation in relation to innovation tends to be intra- and inter-firm rather than in relation to universities, and only five of the fourteen firms in the sample cooperate with local universities. However, the mining firms that are the most significant financially tend to innovate in cooperation with local higher education. The analysis suggests that large mining firms with a high turnover and high innovation spend cooperate with local universities to meet their process innovation requirements, to reduce costs and improve efficiency, as well as enhance regulatory compliance. A specific sectoral demand is evident, with the mining firms that cooperate with local universities ranking these regulatory outcomes more highly than the other sectors. The long history of university interaction is more starkly evident in relation to R&D performing mining companies, which all cooperate, and almost three quarters with universities – but again, a very small total number of very large firms (Table 8).

Case studies reveal this interaction to have specific features: it tends to involve very specific expertise complementary to in-house R&D capability, it is strongly governed by a dyadic contract with strict confidentiality agreements, and it offers sponsorship of facilities and students to the university, in exchange for access to graduates and innovative outcomes in future (Kruss 2006a).

The contribution of universities to the mining sectoral innovation system would thus appear to be well-established. Although it has declined over the past decades, the resource-based sector remains significant beyond its direct contribution to GDP (OECD

2007). The question is whether universities can contribute to create new areas of comparative advantage in global markets.

Growth through productivity: university interaction in the agricultural sector
The agriculture sector has declined in its contribution to GDP over the past five years, as well as in its share of employment. The main focus of government policy has been to shift the sector 'to produce efficiently, generating farm incomes and employment' (OECD 2007: 32), particularly to increase labour absorption in the impoverished rural areas. Innovation to enhance agricultural productivity is critical to address human development issues in South Africa, and exports are critical to growth in this sector, which requires improved competitiveness. Improved productivity is one key element for achieving this goal – and the question is, whether interaction with universities can contribute to such improved productivity.

There were no agricultural firms included in the innovation survey, so we do not have insight into innovative activity in this sector. There is a very small number of R&D performing firms (Table 8), and the total R&D expenditure of R14 million is far lower than the average for the sample as a whole. Agricultural firms are very strongly involved in experimental research (67%) rather than applied (31%) or basic research (4.8%). The firms interacting with universities are more involved in basic and applied research focusing on the biological sciences, and in contrast, the firms that do not tend to be involved in experimental research, focusing in the agricultural sciences. These firms appear to be inserted in networks with a wide range of local and foreign partners.

Research networks are based primarily at research universities with long-standing agricultural expertise, where the university conducts high technology research appropriate to the geographical and climatic conditions of South Africa, increasingly using a biotechnology platform, in collaboration with agricultural associations or large agricultural firms that conduct field trials and testing of new seeds or cultivars, breeding of new animal lines, as well as research support for aquaculture and mariculture (Kruss 2005). Such trends represent emergent conditions for potentially significant new clusters focused on human development needs in South Africa and comparative advantage, but the scale remains in its infancy.

The services sector: contracting in expertise
The services sector represents the largest share of GDP in the South African economy and is now promoted as most promising for economic and employment growth. Distinct trends in innovation-related activities and interaction with universities are evident in the services sector, in comparison with the manufacturing and traditional sectors.

Universities play a limited role in innovation and R&D in the *wholesale and retail sector*, with the lowest proportion of firms cooperating on their innovation, and none on R&D (Table 8). Primarily, medium and small firms interact with universities in relation to product innovation, and there are evidently a few large players who do not cooperate but spend significant amounts on innovation through the acquisition of machinery, equipment and software. The origin of product innovations for 49% of the firms co-operating on their innovation activities was foreign, while the origins of process innovations were more likely to be local (72.8%). More of the university-cooperators in this sector reported that their product innovations originated abroad. A relatively high

number of firms in this sector also reported co-operation with other enterprises within their group, with suppliers, clients or customers and even competitors from abroad, and there is a small group of firms that co-operate with clients or customers in Africa. However, the innovating firms in the wholesale and retail sector that cooperate with local universities report greater levels of success in increasing the range of goods or services, entering new markets and improving the quality of their goods and services that the other sectors (Figure 8).

There are a total of 146 firms in the *financial and business services sector*, mainly small (39.0%) and micro (38.4%) (Table 8). R&D performing firms in the financial services sector report a wide spread of cooperation with their own and other firms in South Africa and internationally. Few innovative firms reported cooperation with universities, but more with clients, customers and suppliers. The proportion of co-operation partners that are foreign, particularly suppliers and clients (including the largest group of partners in Africa), is distinctive in this sector, indicating insertion into global networks.

The association between cooperation and R&D activity in the financial and business services sector is also different to that of the other sectors. The university-cooperating firms spend less on R&D than the non-university cooperating firms. The university-cooperating firms however have higher levels of R&D personnel intensity and focus more on basic research in fields of ICT and engineering sciences. The most significant outcome of innovation activity for firms in this sector that cooperate with universities is the improvement of the quality of goods or services (Figure 8). The university-operators also reported average levels of success in process outcomes than the non-university cooperators, with the greatest difference reported in reducing the use of materials and energy per unit output (a factor that is of least significance for most other firms except those in the mining sector).

Firms included in this sector typically are banks, insurance and investment companies, accounting and auditing companies, but also real estate companies, those engaged in computer and related activities and renting of machinery. It appears that a large proportion of R&D activity is related to software development. South African banks and insurance companies have a history of active technology transfer, learning and adaptation in the face of sanctions, and have innovated new products such as those related to internet security, mobile phone banking and ATM security. Companies have invested significantly in customised systems, for example, banks and insurance companies require sophisticated risk analysis that involves a range of R&D activities, from actuarial services, econometrics, customer intelligence and behaviour, product development, to mathematical modeling and system development. Kahn and Hounwanou (2008) point to these R&D trends as being based on a long history of South African firms as 'early adopters of technology'. The financial and business services sector conducts very specific types of research. They may spend more on R&D to develop large customized systems, and they require stronger internal R&D capacity to facilitate technology transfer and absorption from multiple disciplinary fields.

In short, financial services firms cooperate less frequently than do manufacturing firms, in general, and with universities specifically, but they conduct more R&D than has been commonly realized. Where they do cooperate with universities, the interactions tend to

Burton and Cowan 2002, Klerck 2005, DST 2007). Public initiatives aimed to stimulate innovation and commercialisation in the biotechnology sector, by establishing a network of regional and national innovation centres and incubators, creating national technology platforms (for bioinformatics and genomics, for example), setting strategic priorities and committing considerable public funding and investment. Biotechnology policy represents an instance of a state-driven attempt at policy targeting, to create the conditions for the STE-led emergence of a multi-agent structure in South Africa:

> ....based on the successful development of a technology-specific infrastructure that 'nurses' key precursor firms, which then get metamorphosed into a new sector or industry (Sercovich and Teubal 2008: 13).

small, with potential in a small set of 20 core commercial firms, 12 public research institutions, 9 industry development and venture capital companies and 4 universities (Coetzee 2005).

The first institution, the University of the Western Cape (UWC), is a historically disadvantaged, relatively young university with a strong national developmental and transformation agenda, part of a middle group of research-capable universities with strengths only in niche areas, and with a '*laissez faire* aspirational' approach (Kruss 2005) to managing university-firm interaction. The second institution, the University of Cape Town (UCT) is a long-established, historically advantaged, well resourced university with strong research capability and reputation locally and even globally, with an approach to interaction that attempts to 'harness innovation potential', although there have been recent shifts to a more '*laissez faire* traditional' approach (Kruss 2005).

Table 10 presents a brief overview of 9 cases of university-firm interaction investigated in the field of health biotechnology in these very different universities, in the context of an immature regional and national bioeconomy. What is encouraging is the opportunity embedded in the universities, which display evidence of scientific production that is attracting global firms and research partners. In contrast, the lack of interaction with local firms, and the gaps in the local value chain that could support a local bioeconomy are significant weaknesses. These trends will be illustrated through brief sketches of the cases in the sections below.

Academic entrepreneurs and global firms as customers of university-based micro-enterprises

With regard to *health biotechnology* specifically, given its historical strengths and areas of focus, there is a very small scale of university-firm interaction at UWC[16]. Where it did exist, the scope and intensity of interaction between the university and the firm was very limited, essentially taking the form of university-based spin-off micro-enterprises offering bioinformatics consultancy services to foreign firms.

The staff of the micro-enterprises is academics located in the university. A failed spin-off company was more strongly inserted into the universities' knowledge generation activities, but in two other current cases, the micro-firm and the interaction do not rely on university funding, legal support nor involve post-graduate students, and the claim was made that the firm does not involve the university's time or intellectual property. One micro-firm offers bioinformatics consulting and customizing as its core business, with two members of a close corporation; the other is a start up venture with multiple partners in a network structure, based on identification of a demand for a one-stop service that allows researchers or firms to access biological material, analyse it genetically, and have a bioinformatics component[17].

This form of micro-company is found in many South African universities, and is a typical form of university-based commercial endeavour. It is essentially a vehicle for consultancy work on the part of academics, used to supplement their salaries by

[16] There is however, more interesting and cutting edge work occurring in other sub-fields of biotechnology.
[17] Both are owned by the same academic, a recent immigrant to South Africa from Europe with experience of working in universities in a number of countries.

spending a proportion of their time on private work. The university's main concern is to protect core academic business and satisfy the entrepreneurial demands of researchers. The '*laissez faire* aspirational' approach of UWC suits the germination of this form of interaction as the research policy aims to create conditions that will make good academics stay in the institution, publish and build a reputation.

However, the impact on the university's research reputation and academic profile is likely to be minimal, as consultancy does not typically lend itself to knowledge generation, or publications or the involvement of post-graduate students, the typical university benefits of firm interaction (Kruss 2006b). The scope for growth beyond a micro-enterprise, generating employment and significant products is equally questionable, as is the potential economic impact in the region or nationally. One reason is the absence – or at least, the very small size - of local markets for health biotechnology services and the difficulties of accessing global markets.

So, the failed spin-off company was initially hailed as an exemplar and succeeded in attracting funding from both government incentivisation schemes and a private venture capital company, a coup in a climate where there is little venture capital or angel investment. The firm had some early successes with its bioinformatics software, with reports that one of its products was being adopted by genomic researchers internationally as a standard for analysing gene expression states, and claims of significant earnings by the university, one of the stakeholders. Nevertheless, within a short period of time, the company collapsed. Failure can be explained primarily by difficulties in accessing international markets, although the immediate catalyst was a dispute with a former employee around Intellectual Property Rights (Kruss 2008). Likewise, the consultancy micro-firm currently has 3 customers, based in the United Kingdom, United States, and Sweden, one a large company, the other two based in an academic environment. The new start up venture too, was negotiating with and targeting global customers.

The cases of interaction in health biotechnology at this university, then, represent fledgling, small-scale academic entrepreneurial activity. Interaction with established *foreign* firms is limited to their role as potential customers or clients of bioinformatics consultancy services, and the local market for such bioinformatics services is in its infancy.

Translational research: health biotechnology and interaction

As a strong research university, UCT has developed policies and internal management structures to promote research niche areas, innovation and technology transfer, although there have been recent shifts away from commercialization and towards promoting academic excellence. In contrast with UWC, UCT has a long-established Faculty of Health Science, which, under strong academic leadership the past few years, has grown its research reputation, performance and budget. Unlike UWC, there is a problem of multiple demands on academic clinicians that acts as a constraint, in that the provincial health department as employer does not regard research as a priority, which undermines efforts to balance good research, teaching and clinical work with patients.

The first case illustrates a contract form of interaction between a global firm, an American multi-national medical devices company, and a cutting-edge cardiac surgery

research unit, a well-established niche area for UCT. The senior academic leading the research unit, a European, transferred an existing contract agreement and set up the research unit when he relocated to South Africa. It is a longstanding form of research outsourcing, based on a generous funding agreement in exchange for IPR that many researchers would welcome, but that is seldom found today, and indeed, that is itself changing and at risk. Over the years, there has been significant sponsorship and endowment of infrastructure and facilities by the global firm. The university gained a world class research infrastructure and funded research posts, and the projects gave rise to an extensive number of publications and post-graduate students, all financed through the firm's research contract.

The returns of the cutting edge 'new to the world' research are not insignificant, but they have not yet been turned into marketable products. The research unit has yielded 18 US patents from their research, with the UCT researchers as inventors and the company as assignees, in relation to tissue engineering. The first product was developed 3 years ago, related to tissue engineering of heart valves and arteries instead of using plastic valves. It is currently in clinical trials, which are reportedly very convincing and likely to succeed, going into final phase trials coordinated by the company (with the university conducting a paid clinical study). The company has sold the rights to an investor group who have started another American company to commercialise the product.

The single largest constraint identified by the researchers is to attract doctors interested in the biosciences and in conducting research, and to attract local specialists such as polymer scientists and biologists (the solution has been to attract staff from Europe). One reason offered for these constraints is the national health policy shift of resources towards primary health care, away from tertiary medicine and research, in line with equity and human development goals.

A change in global knowledge flows has seen large multinational corporates withdrawing from conducting their own research, whether in house or contracted out, in favour of acquisitions of start-up companies that have conducted innovative research. With the risk of the preferential agreement ending, the research unit is seeking funding from local and international funding agencies, as well as establishing a fledgling start-up company to develop a catheter based heart valve that can be implanted without specialized cardiac surgery expertise, particularly suited to conditions in Africa.

The case illustrates the potential scientific excellence that can attract global firms to support cutting edge research in a South African university, but the impact of shifting relationships in global knowledge production systems, as well as the tensions between prioritization of expanding access to health systems in South Africa and the imperatives of frontier science, in conditions of limited financial resources.

A second research institute has its origins in the same set of adverse conditions for the academic-researcher-clinician, but represents a different resolution of the tensions – the creation of an independent university owned company in which commercial research ventures are used to cross-subsidise strategic and translational community-based health research with a social development goal.

Unlike the university-based micro-firms at UWC, for this proprietary limited company wholly owned by UCT, the dividends are not declared, and any surplus generated is used to fund the company goals – strategic research. There is no commercial benefit,

and it operates in effect as a not-for-profit company. The strategic research is informed by a clear view of the specific health needs of South Africa and a commitment to community-based research. A concept of 'knowledge translation' has been adopted to guide their approach, which refers to translating medical advances with a clinical bent into applications in the context of Africa with its unique limitations. A Knowledge Translation unit is involved in a World Health Organisation global alliance, and is increasingly a means of gaining funding for development work, spearheading models of integrated care, rolling out models locally in various provinces and in SADC countries. To 'pay the rent' and find resources for research, both human and financial, the unit's 'opportunistic' work is commercial clinical drug trials for foreign pharmaceutical companies.

This institute is thus a hybrid public-private venture, a research institute structured as a not-for profit company, which appears to be succeeding in terms of its goals, if the growth in staff and funding resources is an indication. The interaction with (primarily foreign) firms takes two main forms – large company sponsorship and donations for infrastructure and facilities, including endowment of a purpose-built building, and large multinational companies as clients of clinical trial services. It represents a positive 'spot of interaction' in that the purpose and expertise of the research institute, the university, the firms and the patient communities interact to mutual benefit.

There are a further three similar cases based in a newly created post-graduate research centre in the Faculty of Health Science. This institute has an explicit orientation to solving the infectious disease problems of Africa for which there are not sufficient solutions globally, and in particular, it aims to address the gap of technology transfer, based on the recognition that local expertise and research is vital to apply the existing body of knowledge on infectious diseases. It too has promoted a concept of 'translational' research, in this case meaning that the researchers work across the entire knowledge chain – they conduct cutting edge basic science to determine the origins of diseases, then on this basis move to drug development, development of new diagnostic tools, effective vaccines and so on. Finally, they attempt to take these new interventions into clinical research and translate them to the 'bedside', improving health and the quality of life of the general population.

The case of an HIV/AIDS vaccine development programme is very different to the others studied, as it involves indirect interaction with large local energy, transport and mining firms, government and the European Union, as sponsors and donor partners to fund research on HIV/Aids vaccines so critical to national health agendas, through the vehicle of a national funding umbrella body.

The research group has worked as an open innovation network, building a multi-disciplinary team to collaborate and contribute their specific expertise to extend the reach of the group, achieve critical mass and create new technology platforms. After a number of years, the project is now at a point where they are ready to test two vaccines. They have approval from the FDA in the United States and are awaiting approval from the South African Medicines Control Council to begin testing and conducting the final potency assessment in the Phase 1 clinical trials.

The tangible product of the project for the university is two vaccines now ready for clinical trial, and the critical mass available to train students and produce publications, as well as a Good Practice Lab (GLP) facility which they can offer as a revenue-generating

service in future. If successful and commercialized, the vaccine could be marketed elsewhere, but the research group holds the rights in South Africa, to ensure that there is access to the IP and sharing in the interests of public health (this group were committed to the public health benefits rather than commercialization).

However, at a critical point in the process of moving to clinical trials, the group is experiencing severe constraints that relate to a lack of maturity in the national system of innovation. First, the government department of science and technology has stopped using the national funding umbrella body as the vehicle to channel funds, leading to a lack of predictability in the flow of critical research funds, and placing the programme under threat. The case points to a lack of predictability of process in government linked public funding, coupled with a lack of expertise in government departments and support structures to provide scientific leadership and vision to a major project like vaccine development. Second, the group has experienced constraints in relation to gaps in the local supplier value chain. Insufficient local capacity in the private or public sector to support the manufacturing of vaccines or small pilot lots for trialing has driven the group to seek interaction with foreign companies to by in this expertise. South Africa historically had significant vaccine manufacturing capacity, built up as part of the apartheid self-sufficiency science agenda. However, Good Manufacturing Practice guidelines changed in the 1980s, and the facilities needed upgrading. The required funding was not forthcoming, and there was a delay as government tried to set up public-private funding partnerships, which took almost ten years. By then, the manufacturing facilities were so out of date that they could not be upgraded, many experts left, and vaccine capability was lost. It was no longer cost effective to manufacture, as vaccines could be purchased more cheaply elsewhere than they could be manufactured locally. An attempt to use government funding to leverage new vaccine manufacturing capacity is still in its infancy. Third, a related gap in the value chain is reliable local Good Practice Lab (GLP) facilities. The main purpose of such a facility is to test the potency of the DNA vaccine, which is a major regulatory requirement and has to be done every 6 months. One of the achievements of the research group arose in the course of making a virtue of a necessity, when a local consultant failed to offer reliable services, and the research group established its own GLP facility, the only one at a university in South Africa. Fourth, finding reliable foreign suppliers of services was a difficult process that has threatened to set the research back, when firms could not deliver what they had promised, or where sold and closed down to realize investments before they could fulfill their contractual obligations. The research group has learned to undertake more thorough due diligence prior to contracting services, but this is exacerbated by distance from global suppliers. Fifth, in terms of what South Africa and the research group are likely to need in the future, because a local vaccine manufacturing sector does not exist in South Africa, should the vaccine work, it is likely to be produced in the US or elsewhere such as India or Brazil – a major systemic weakness and missed opportunity.

In this case, interaction with firms takes two very limited forms, large local corporates as co-funders of a public vehicle to coordinate vaccine research, and small foreign biotechnology firms as service manufacturers of vaccines for clinical trials, paid for by international donors. The case illustrates the strength of local scientific expertise in interaction with global and local research networks, and the ways in which universities can contribute to national development by addressing a health need that is the most significant constraint on future development in South Africa.

The final two cases may be dealt with briefly to reiterate and amplify these trends. After many years, and based on a number of global collaborative research and funding networks, a UCT research group in collaboration with partners at a UK university solved the problem of identifying the three dimensional structure of the protein, angiotensin converting enzyme (ACE), representing research at the frontiers of science (first published in Nature). On this basis, the group proceeded to identify a suitable compound to develop a new second generation drug to treat hypertension, again, through global and local research networks. At this point the research group encountered significant systemic weaknesses, in the difficulties of raising sufficient funding for an early stage venture in South Africa. The work was considered too early stage for multinational drug companies, government funding vehicles did not extend that far in the cycle, there are no local drug discovery biotechnology companies, and hence, difficulty in attracting venture capital from the few local investor firms.

Ultimately, with strong university support given its niche area of drug development, the group has succeeded in obtaining funding from a public biotechnology regional innovation centre (BRIC) intended to stimulate innovation and commercialization in the sector. In terms of this agreement, the group will form a new South African based subsidiary spin-off company to which the IP will be assigned, rather than the university, although the university and the academics will be shareholders. A US based company the group formed earlier in the patent process will operate as a virtual entity, in that it will fund research for the development of new generation ACE inhibitor drugs undertaken by the UCT research group. The executive of the South African based company will be a Cape Town business person experienced in project management and fundraising, with no university experience or base, a condition imposed by the BRIC to safeguard their funding. It is likely that this small spin-off company will take the group through refining the compound and perhaps Phase 1 trials, but thereafter, they will need a pharmaceutical or major biotechnology company partner to develop and license out the product. The main aim for this company then, is to develop the IP and sell, to realize the initial investment.

This research group has been successful in terms of its goals of proceeding through the translational pipeline, but it is now entering a high risk stage. The case highlights the complexity of remaining within the university environment once there is a move beyond basic research towards commercialization, in which case issues of IPR, financing and business management become paramount, as well as the difficulties facing high technology start ups in South Africa.

The final case represents an early stage example, of an entrepreneurial academic, also recently immigrated to South Africa, with a strong commercialization agenda, based in a publicly-funded technology platform to promote proteomics and genomics capacity, fund. Based on the assumption (and the leader's prior experience) that academics are not well equipped for commercialization, the networked research team is establishing a commercial venture from the outset, with research aimed at identifying new diagnostic and prognostic markers for colo-rectal cancer that are non-invasive. The intention is that the commercial operation will be based in the United States in order to access the scale of investment required, with the research operation, for which they are in the process of setting up legal status, in South Africa. Essentially, the US firm is structured so that it invests its financial resources in South Africa, in effect, paying the technology platform and the academic group to conduct research at UCT. Again, the absence of local biotechnology firms as venture capital or investment partners is notable.

Each case at UCT Faculty of Health Sciences represents an instance of the ability to 'harness innovation potential' of university based research. The cases all involve 'frontier science' new to the world and oriented to the human development needs of South Africa, the SADC or sub-Saharan Africa. The research conducted has intrinsic value, whether in relation to the HIV/Aids virus, heart disease, hypertension or cancers. The new discourse of 'translational' research, with its variant interpretations, provides a focus for developing a new research culture and enhancing strategic capability in the faculty of health science and in the university, and the university benefited reputationally in terms of publications, students and evidence of its contribution to address national health priorities. However, very few local biotechnology firms are involved in interaction, whether as sponsor, customer, supplier of services, or partner in a start-up company.

Health biotechnology as an emergent 'spot of interaction'

The trends are very specific to the health biotechnology sub-sector, but the case studies provide fascinating insight into the complexities of traversing Phase 2.

Health biotechnology has been targeted and supported by national and regional government, and by individual institutions of the national system of innovation. The potential of the scientific advances in the sub-sector to address critical human development needs in South Africa and sub-Saharan Africa, to tackle health problems for which there are insufficient solutions globally and regionally, is irrefutable.[18]

At this stage, however, health biotechnology represents one 'island' of innovation activity *within the higher education system* that enables insertion into global scientific and research networks. The differences between the two universities raise questions about the lack of diffusion and depth of scientific capacity across the segmented higher education system. The concentration of capacity at UCT (and the fact that so many key research group leaders are foreign), reflects that science and technology thresholds have not yet have been reached sufficiently across a differentiated, flexible higher education system.

Yet, while it is encouraging that South African higher education has levels of scientific production that are sufficiently strong to attract global firms as sponsors, customers or partners, the local productive sector is not able to take advantage of the latent opportunity inherent in this research and knowledge generation capability. At this point in time, the health biotechnology sub-sector does not represent an instance of a 'spot of interaction' between local universities and local health-related firms as a basis to grow competitive advantage. And it is unlikely that university-led commercial ventures can drive the process without a core local productive sector with key capacities along the value chain. Such a mismatch between the national knowledge and the firm innovation subsystems are typical of the developing world (UNIDO 2005)

These weaknesses illustrate the challenges of developing conditions and capacity for, in this case, science-led firm selection, and for creating an emergent new product class,

[18] Hence, biotechnology has been reconfirmed as a priority sector in the new 10 year plan of the Department of Science and Technology (DST 2007).

given fragile links within the South African national system of innovation that need to mature over time.

Targeted strategic policy intervention could strengthen the nascent health biotechnology sub-sector in relation to the national system of innovation. The analysis identified the following areas for intervention, for example:

- the need for greater security and seamless links in public funding cycles
- the need for incentives to attract specialized high-level skills
- the need to build local technical, regulatory and manufacturing capacity along the value chain of vaccine and drug development
- the need for local private venture capital and investment agencies
- the need for academics to access external entrepreneurial expertise, particularly in relation to IPR protection and financial regulations
- the need to build capacity of government departments and public funding or service delivery vehicles to implement programmes more effectively.

The implication is that policy interventions should not be imitative of global best practice, but that policy learning should be informed by such contextually and sectorally specific analysis.

CONCLUSION: UNIVERSITY-FIRM INTERACTION AND THE CHANGING ROLE OF UNIVERSITIES IN SOUTH AFRICA

The final section of the report returns to consider the implications of the empirical analysis of university-firm interaction for policy interventions that can address the changing role of universities in knowledge-based economic growth, innovation and development in South Africa.

Policy to support traversing phase 2

South Africa's task of catch-up has been categorized as typical of a country attempting to traverse a 'middle' developmental phase, of creating conditions for firm selection and specialization to access global markets, to strengthen emergent networks and innovation activity - and simultaneously, to resolve historically determined lock-ins in human development, evident in high levels of unemployment, poverty and inequalities in education and health.

In this context, the demands on higher education are multiple, but the study has focused specifically on the demand for higher education to contribute to firm's technological upgrading and to increasingly effective selection and specialization.

Analysis of university interaction with firms on their innovation and R&D activities revealed patterns of open innovation networks akin to those of catch-up and developed countries, particularly on the part of larger, more technologically intense firms with evidence of absorptive capacity. Unlike many other developing countries, where the productive structures do not demand sophisticated knowledge and technology, (some) universities are contributing to (some) firms' technological upgrading.

However, these tend to remain 'islands' of innovation, and innovation networks are not widely diffused across the economy to a large number of firms or entire industries. There is evidence of strong sectoral differences that require a great deal of further research: historical patterns of interaction between local universities and firms in mining and agriculture, inter- and intra- firm interaction both local and foreign firms in the financial and business services sector, and emerging new complex patterns in the manufacturing sector that require disaggregation by sub-sector and field to identify specific 'spots of interaction' that can be nurtured.

Case studies in health biotechnology, an emergent sub-sector targeted for public policy support, suggest that at this stage, it does not represent a 'spot of interaction' between universities and local health-related firms. The levels of scientific production within the higher education system are sufficiently strong to enable insertion into global scientific networks and to attract global firms, so that the higher education system is ahead of the local productive sector, which is still in its infancy with significant gaps in critical value chains. The analysis identified systemic failures in the institutions of the national system of innovation that constrain the development of capabilities that could support the emergence of a dynamic, competitive health biotechnology sub-sector.

Such contextually specific analysis of the stages of development in general and in specific sectors can inform policy interventions. A full analysis of policy implications would require engagement with the detail of present national and sectoral policy

structures and mechanisms relative to interactive practice, which of necessity is the subject of a separate study. Here, the evidence in support of a combination of horizontal and targeted policies is briefly marshaled.

Horizontal policies to address social welfare and higher education lock-ins
Horizontal policies are increasingly recognized as important to support the conditions for knowledge-based development in countries like South Africa to avoid 'falling behind' or stagnating rather than catching-up. High income concentration and uneven income distribution are identified as a critical lock-in on technological progress in immature national systems of innovation (Albuquerque 2007, Altenburg 2008).

> Income concentration is related to demand, but it is also related to supply factors of technological innovation (inequality in education, general and technical, limits to university access, access to credit, etc): these income distribution-related factors block the spread of the success cases throughout the whole economy (Albuquerque 2007: 14).

Horizontal policies to address inequality, poverty reduction and social welfare, the unresolved human development demands highlighted in the analysis, could break low-equilibrium traps and binding constraints on the national system of innovation in South Africa.

Government in South Africa has increasingly emphasised these challenges, in the context of steady growth since the early 2000s. Macro-economic policy and a more expansionary social budget have prioritized tackling the dualism of the economy and addressing binding constraints, particularly unemployment, education, skills and human resources development (Mlambo-Ngcuka 2006, PCAS 2006). Such priorities become even more significant in the current global economic crisis and looming recessionary conditions in 2009. A commitment to cross-sectoral coordination between government departments is evident in the establishment of cabinet 'clusters' (Kraak 2007). However, the capacity and capability within government departments and public intermediary agencies to effectively implement policies based on analysis of existing local conditions and to promote coordination and interaction is embryonic and itself a potential binding constraint (Kraak 2007, Kruss and Lorentzen forthcoming).

The analysis also highlights the significance of horizontal policies to grow and strengthen knowledge institutions across the higher education system, both quantitatively and qualitatively, to reach levels of critical mass. The small scale of interaction, and the differential capability of universities with distinct legacies to interact with firms points to the significance of diffusion of scientific and organisational capabilities more widely across the higher education system, so that the system has the capacity to reproduce itself and produce more graduates with the skills required by firms. Recent analyses of stagnation in South Africa's innovation performance has led to a call for better policy sequencing and prioritization, beginning with a horizontal policy focus on the development of high-level skills to address this major constraint on technological innovation (Kaplan 2008). Here too, is considerable ongoing policy effort on the part of government, individual institutions and higher education associations, to grow and strengthen knowledge institutions, which have yet to take effect. The case study analysis highlights the importance of identifying and addressing systemic failures and disjunctures on a regular basis. In short, the strategic level of policy-making required in a dynamic and rapidly changing local and global environment needs to be developed more

strongly in South Africa. Strategic policy-making requires ongoing re-assessment in the light of new strategic priorities and system failures, based on knowledge of institutional and contextual specificity (Sercovich and Teubal 2008, UNIDO 2005).

Targeted policy to support firm selection
Traversing phase 2 requires a shift to targeted policies that can trigger and sustain the emergence of new multi-agent structures and higher level organisations, whether a cluster, a new sector or sub-sector or market (Sercovich and Teubal 2008).

The kinds of targeted support required to address system failures and constraints in the emergence of a health biotechnology sub-sector in South Africa were highlighted in Section IV, as one illustration.

The study's analysis of patterns and trends of firms' cooperation with universities on their innovative and R&D activities across the national system was only a first step. It highlights the significance of detailed studies of selected priority sub-sectors with potential and existing comparative advantage, particularly sub-sectors in which it is evident that there is an existing group of highly capable firms that cooperate with universities on their innovation and R&D activities, or that display features of open innovation networks more strongly. It also highlights the importance of identifying and problematising the potential opportunities where innovation chasms exist, where there are scientific specializations and latent opportunities in the universities that the productive sector is not using sufficiently. The trend that large firms are more likely to cooperate with universities highlights yet another area for investigation and strategic re-examination of existing targeted policies in South Africa – the contribution of universities to support technological upgrading in small and medium firms.

A responsive university

The main conclusion from the study is that in order to contribute to 'keeping-up' and catch-up, to the task of traversing phase 2 successfully, universities in South Africa should focus more strongly on consolidating their traditional strengths as a basis for expanding their contribution to build a more mature national system of innovation.

The global shift to a new 'third mission', of a role for universities in economic and social development, and the notion of an 'entrepreneurial' university (Clark 1998, 2003, 2004) impacted in South Africa since the 1990s. A lively debate ensued at the time, as to the most appropriate new model for the changing university in South Africa (Subotzky 1999, Kraak 2000, Muller 2001, Singh 2001, Gewers 2001, Favish 2003, Ravjee 2002, CHE 2002). A few universities explicitly adopted and actively pursued new models of the entrepreneurial university (Kruss 2005a). More generally, in practice, the 'third mission' tended to be interpreted in terms of a narrow vision of entrepreneurialism, in terms of short-term, market-driven commercial goals, to raise income for the university in the face of public funding cuts. Such commercialization strategies carry high risk, even in developed countries (Cargill 2007), exacerbated under conditions of scarce resources as in South Africa. The differential capacity and segmentation of the higher education system means that very few universities have the capabilities required for launching successful high technology start-ups and commercial ventures.

Universities are already key cooperative partners in a number of sectors, responsive to firm demand, complementing firm capacity and contributing to firm upgrading – but there is considerable scope to expand this role. At this stage of South Africa's development, given multiple demands and imperatives, universities would be better served by proceeding on the basis of what they do best – teaching and research – to build open innovation networks with firms and other knowledge producers.

The key is to expand the complementary role of university-based research and teaching where there is latent opportunity, where potential firm demand matches existing or emerging university scientific strengths. The analysis provides a first step to identify such 'spots of interaction'. It is thus important for higher education institutions themselves to develop the capability for strategic 'intelligence gathering', for analyzing where the potential matches are between their scientific strengths and local firm demand, and how they can access public and private support. The emergence of new hybrid forms of private-public research institutions illustrate one possible mechanism whereby universities can cooperate with firms in a mutually beneficial manner, and contribute to social and human development goals, as does the notion of 'translational research'. Such institutional innovations are informed by understanding of local conditions. Unreflective imitation of 'best practice' from universities in the United States and United Kingdom or Europe will not promote university-firm interaction that serves South Africa's task of traversing phase 2 to catch-up. Rather, a new national model of a *responsive university,* with research and teaching as a foundation for interaction, encompassing the core developmental tasks, can be elaborated as a more contextually appropriate alternative.

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