OPEN INNOVATION IN SOUTH AFRICA: CASE STUDIES IN NANOTECHNOLOGY, BIOTECHNOLOGY, AND OPEN SOURCE SOFTWARE DEVELOPMENT

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In the era of open innovation, the capability to conduct collaborative research and development has become a key indicator of absorptive capacity and innovation competitiveness. However, the literature addressing open innovation has a focus on developed economies. New evidence from the South African National R&D Survey, together with supplementary data, make it possible to gain a greater understanding of the structure of open innovation in nanotechnology, biotechnology and open source software in the South African context. Findings from a comparative analysis include: the identification of collaboration-intensive R&D networks whose structures are influenced by the characteristics of each technological platform; linkages between localized innovation networks and global innovation networks; and distinct patterns of expenditure, sectoral distribution and geographical location characterizing each of these technologies. The paper concludes with some suggestions for policy applications for these findings as well as directions for further research.

Keywords: open innovation, biotechnology, nanotechnology, open-source software

1. INTRODUCTION

Following the introduction of the concept of open innovation by Chesbrough in 2003, it has become widely accepted that the previously dominant model of internally focused and controlled innovation has in many instances lost its competitive advantage over open modes of innovation that utilise both internal and external knowledge sources to advance firms' business models. Open innovation framed a new way of understanding partnerships and alliances within innovation systems, both in terms of external collaboration practices and internal management decisions.

However, the overwhelming majority of research in this area has focused on open innovation in developed economies. While this is not surprising, since most innovation activity takes place in these economies, it does not speak to the potential of open innovation to grow developing economies and contribute towards addressing their social development too.

This paper therefore offers case studies in open innovation in South Africa, with a focus on nanotechnology, biotechnology, and open source software development. These case studies were chosen because they have precedents in the open innovation literature, because as early-stage technologies they have great strategic potential, because they have public policy contexts in South Africa, and because new data have recently become available that can describe collaboration and R&D activity in these areas.

Moreover, policy in South Africa has been developed in the context of a paucity of data that might shed light on how open innovation networks operate in these fields. The aims of this paper are therefore to understand the structure of open innovation in these fields in the context of an emerging economy, and also to provide evidence and analysis that could inform policy-oriented research.

The first part of this paper sets out the analytical framework of open innovation and its role in horizontal and multidisciplinary fields of science in the context of a developing economy. The second part sets out the policy context in South Africa. The third part discusses data and methodology. The fourth part presents the findings. The final section draws conclusions.

2. ANALYTICAL FRAMEWORK

The analytical framework for this paper is based on the idea of open innovation, a term first coined by Chesbrough in 2003. This model suggests that "firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology." (Chesbrough, 2003, p. XXIV). This idea had precedents in innovation literature: Cohen and Levinthal's understanding of absorptive capacity included the competence of firms to absorb ideas from outside the firm. Proponents of innovation systems thinking such as Rosenberg (1982), Lundvall (1992), Pavitt (1998) and von Hippel (1988) have perceived inter-organisational learning as a key innovation competence. However, Chesbrough introduced a more systematic analysis of organisational innovation and corporate decision-making with respect to inter-organisational collaboration. Chesbrough concludes that in a world of increasingly large and complex knowledge resources, the ability to leverage both internal and external knowledge to suit a firm's business plan will become increasingly important, both in terms of innovative outcomes and in terms of firm-level competitiveness.

Research examining open innovation systems has largely focused on developed economies. The research question this paper seeks to answer is therefore: what kind of open innovation structures exist in the South African context? To this end we examine case studies in nanotechnology, biotechnology, and open source software development. These case studies were chosen for several reasons. Firstly, there is their strategic importance as early-stage technologies with the potential to open up new products and markets, to stimulate economic development, and to contribute towards meeting development challenges (Hung and Chu, 2006).

The latter is particularly important in the context of a developing country: nanotechnology can contribute to new methods of energy production and storage, water purification, agricultural production and storage, medicine and health (Maclurcan, 2005). Biotechnology can contribute towards improved food security through the development of genetically engineered crops, improved health care through improved vaccines, diagnostics and treatments, as well as finding applications in agro-processing, water and sanitation, and nutrition. Open source software can be used to replace proprietary software of almost any form, cutting the prohibitive cost of software and bolstering ICT development.

Secondly, the characteristics of the three technologies will make for an interesting comparison. Each have different barriers to entry, both financial and in terms of skills. Each has different degrees of multi-disciplinarity: biotechnology is highly multi-disciplinary, nanotechnology is multi-disciplinary but to a lesser extent, while open source software development is arguably in most cases not multidisciplinary. We can draw on contextual information and data to examine whether these factors influence on the 'openness' of firms seeking to develop these technologies. These fields also have some elements in common: each can be seen a horizontal technology. For the purposes of this paper a horizontal technology is defined as a technology that can find application across many economic or industrial sectors. By this understanding, each of our case-study fields is a powerfully horizontal technology, not only in their current range of applications, but in their anticipated future roles as revolutionary technologies that will open up new products, markets and benefits.

Thirdly, there is a history of literature examining open innovation in each of these fields, for example Fetterhoff and Voelkel (2006), and Nikulainen (2008) in biotechnology and nanotechnology respectively, and West, Scott and Gallagher (2006a, 2006b), Simcoe (2006), and Graham and Mowery (2006) in open source software development. This literature has established the potential of open innovation to advance firm profitability, create new markets, and leverage internal and external innovation capabilities to suit open innovation business models in each of these fields, although these analyses almost entirely refer to open innovation in the developed economies.

A fourth reason is more pragmatic. In South Africa, R&D data are difficult to access. Only those working directly in survey fieldwork have access to data in a way that allows for meaningful analysis. In principle further access can be granted by survey administrators, but in practice this is often not the case. The data used in this paper were accessed because in the case of biotechnology and nanotechnology the author was working within the survey fieldwork staff, and in the case of open source software the author collaborated with someone who was. The data set therefore represents the only detailed set of R&D survey results for technological platforms that may be useful in further understanding open innovation networks as they relate to multi-disciplinary and horizontal technologies in South Africa.

Finally, each of these technologies have a substantial policy context in South Africa, although these policies have been developed largely without data relevant to understanding open innovation in the development of these technologies. One of the aims of this paper is to make a contribution here. Thus before entering a discussion of methodology and findings it would be useful to briefly discuss domestic policy.

3. THE POLICY CONTEXT

Each of these technology platforms has a dedicated policy response from the South African government, although all of these are comparatively recent. Firstly, nanotechnology is seen as offering great potential for emerging economies, as well as certain threats, such as those inherent in the process of creative destruction (Romig et al, 2007). There has also been considerable public interest in the potential of nanotechnology (Campbell, 2003; Campbell, 2006). This is despite nanotechnology's relatively short history: very limited nano scale microelectronics research began in South Africa in the late 1980s, but nano scale research only began to really develop in the late 1990s (Venter, 2003). By 2002 there were sufficient projects and researchers to provide momentum for the establishment of a professional group for the field - the South African Nanotechnology Initiative (SANi) - with the aim of coordinating R&D to obtain major funding, as well as creating an international networking hub for South African contact points in bilateral and trilateral nanotechnology programmes with the EU, Iran, Japan, South Korea, India and Brazil, amongst others (Campbell, 2006). SANi engaged with the South African Department of Science and Technology, suggesting that the country should play a fast-follower role, learning from the basic research performed in well-resourced developed countries and using local capacity to carry out applied research and develop commercial applications as has been successfully carried out in China. This engagement culminated in the launch of the National Nanotechnology Strategy in 2006, which set out to invest R450 million in nanotechnology R&D over three years (Department of Science and Technology, 2006). The strategy focused on the establishment of characterisation centres to provide researchers with the necessary advanced instrumentation and infrastructure, the establishment of networks to increase collaboration, support for postgraduate research, and support for certain flagship projects. Social development aspects concentrated on water, energy and health, while commercial applications focused on chemical and bio-processing, mining and minerals, and advanced manufacturing.

Biotechnology during the apartheid years received little state support (Cloete et al, 2006). However, perceptions changed after 1994. Biotechnology was seen as having the potential to grow the economy by creating more efficient industrial processes and innovative new products (Bisseker, 2003), and was also seen as a tool to help address development challenges (Cloete et al, 2003). This lead to the adoption of the 2001 National Biotechnology Strategy (Department of Science and Technology, 2001). This resulted in the establishment of a network of four publicly funded biotechnology research support centres, a national bioinformatics network, and two technology incubators for biotechnology start-ups. However the effectiveness of these public institutions has been questioned (Jordaan, 2007).

Advocates of open source software propose that it has considerable benefits for emerging economies, including lower costs, increased propensity for local capacity development, greater flexibility for context-sensitive customisation, and increased independence from the hegemony of large software firms (Camara and Fonseca, 2007; May, 2006). The advent of democracy in 1994 was also the starting point for current policy regarding open source software development. The new government aimed to use information technology as an enabling factor to improve service delivery, and was also attracted by its potential to cut costs, reduce financial outflows, and develop local capacity. After a long process of research and consultation (for details see NACI, 2004), the Department of Public Service and Administration (2006) adopted a Policy on Free and Open Source Software Use for South African Government. This in principle made open source software a nominal non-negotiable base for the government ICT environment, with focus areas on implementation, migration, development, open format licensing, and the promotion of the wider use of open source software. Each of these themes defined a particular phase in an overall implementation plan. However, in contrast to the nanotechnology and biotechnology strategies, no financial commitments were made, and there is little or no evidence of implementation.

A common weakness in all the policy-making processes indicated above is a paucity of data relevant to understanding open innovation. The effect of this is that policies are not strategically targeted at interventions that might support specific open innovation processes, but rather provide general platforms for collaboration and general support for infrastructure and flagship projects. Thus one of the aims of this paper is to provide some evidence and analysis for policy, so that policies can be targeted to be more supportive of open innovation in these technologies.

4. DATA AND METHODOLOGY

The core data set for this paper is drawn from South Africa's national annual Survey of Research and Experimental Development Inputs, performed by the Centre for Science, Technology and Innovation Indicators for the national Department of Science and Technology. This survey is conducted according to the OECD's standardised methodology as detailed in the Frascati Manual (OECD, 2002). Specialised questionnaires are directed at firms, government, science councils, higher education institutions and non-profit organisations. The statutory survey requires that all organisations performing research or experimental development return a survey questionnaire containing basic economic data and extensive R&D data. Coverage of the survey is very high among government, higher education and public research institute respondents. Coverage of firms is achieved through a purposive methodology, in which all firms that could potentially be involved in R&D in South Africa are targeted in the business sector survey. While this cannot be comprehensive, especially among smaller firms, the major players are included and estimates are made for smaller players who are not. The survey is thus representative of the large majority of R&D conducted in the country.

In recognition of the importance of the three technology platforms studied in this paper, the Department of Science and Technology included in the 2005/6 survey dedicated questions for nanotechnology, biotechnology, and open source software development. Survey respondents were asked to estimate the percentage of their internal R&D expenditure allocated to these technologies. The organisations that answered positively to one of these questions formed the sample for this paper. This represents the majority of biotechnology and nanotechnology R&D in South Africa.

However the measurement of open source software development poses special challenges, since a large proportion takes place outside the formal working environment, and thus easily escapes measurement. A survey of open source software developers in Brazil found that approximately 40 percent of developers had a paid job to develop open source software (Stefanuto & Salles-Filho, 2005). A similar proportion was found in the responses to a European survey by Ghosh, Krieger et al (2002). In both cases 60 percent of open source software developers were performing their work outside of the formal business environment, the so-called 'weekend' and 'basement' developers. This finding points to the fact that much of the work within the open source development area is outside of formal industry and therefore may not be effectively tracked and counted in surveys. Another difficulty is that open source software development falls on the margin of what can be defined as 'software development'. The OECD Frascati methodology (OECD, 2002) describes software development as activity that produces novel software or adaptations leading to novel functionality in existing software. Interviews with executives from four of South Africa's largest software development firms (Gastrow, 2009b) highlighted that this resulted in difficulty in measurement, as much of their development activity would fall on the border of this definition. For example, customization of existing software may introduce new functionality, but classifying this as 'development' requires a careful inspection of the novelty of this functionality and whether this falls within the Frascati manual's definition thereof.

Despite these caveats, the result is the availability of three relatively comprehensive and accurate data sets describing R&D activity in each of these technologies. The findings below illustrate the expenditure, collaboration activity, and geographical location of R&D in these areas respectively. Some additional survey data are not made available for confidentiality reasons - here however we have supplemented with publicly available data. However most of the other data points from the survey cannot be used because of the structure of the questions: only expenditure data were directly tied to the specialized question. Other data regarding as human resources profiles, types of expenditure, research fields, and industrial sectors cannot be directly attributed to one of these technologies, unless they indicate that one of these technologies account for 100% of their R&D expenditure, in which case all the data would relate directly, or additional fieldwork and interviews are conducted to establish such connections.

Nonetheless, the data at our disposal are useful. Information about the sample tells us something about what the institutional spread of R&D activity is. Expenditure data tell us where the main loci of R&D activity are. Supplementary data provide useful contextual information. Collaboration data are perhaps the most useful, providing several means by which to explore the structures of collaboration modes. Finally, data regarding geographical location provide an additional lens through which to understand these networks. Taken together, these analyses can be used to develop a more coherent picture of open innovation in each of these sectors in South Africa. However, it must be noted that research into open innovation requires both an examination of external R&D collaboration structures and of internal R&D management practices. This paper has a focus on the former, but aims to inform further research in the latter.

5. FINDINGS

Table 1 indicates the size of the sampling frame and sample for each technology. The sampling frame is the total set of respondents to the national R&D Survey, while the sample for each of the technologies is the set of firms that answered positively to the dedicated question in the survey. The data are split by sector: firms, higher education, government agencies, Science Councils (parastatal research institutes), and non-profit organisations. In some cases these overlap, for example higher education institutions or Science Councils that perform R&D in two or three of these areas.

Table 1: Sampling frame and sample from National R&D Survey 2005/6

Sector	No. of R&D performing organisations in the sampling frame	No. of R&D performing organisations in sample		
		Nanotechnology	Biotechnology	Open Source Software
Business	607	8	22	20
Science Councils	24	3	6	1
Higher Education	43	14	18	8
Not For Profit	28	0	0	8
Government	88	0	4	1
TOTAL	790	25	50	31

The three technologies have distinct patterns reflected in the sample. Nanotechnology R&D takes place at several of South Africa's universities, as well as a small number of firms and three public science institutes. The biotechnology sample is twice the size of the nanotechnology sample, perhaps because of the lower barriers to entry compared to the high capital and skill requirements of nanotechnology R&D. In biotechnology there is also a higher concentration of firms in relation to universities, as well as a more significant number of public research institutes and government agencies. Open source software development is even more concentrated in firms. Again this is not surprising, since this has even lower barriers to entry, and software development does not require the same level of basic research skills and infrastructures.

Table 2 shows the aggregated expenditure data for the sample. It is important to note that the Frascati methodology measures *in-house* R&D. For example, private-sector funded R&D performed at universities would be included in the data reported by the latter. The data therefore reflect the actual performance of R&D, rather than funding or the control of the resultant IP. Expenditure on outsourced R&D is measured separately, but response rates to outsourcing questions are low. However, in-house expenditure data are still revealing. In the nanotechnology sample there are twice as many universities as firms, but the firms spend 66% more than the universities. In other words, it is the firms that have the large budgets, and which may therefore set the research agenda - a relationship which is also reflected in the contextual information below.

In biotechnology, on the other hand, more R&D expenditure takes place at universities than at firms, even though there are more firms in the sample. This is in line with the nature of the technology, where basic research takes place at universities, but where the majority of biotechnology R&D performing firms are start-ups, and often also spin-offs aiming to commercialize intellectual property developed at universities (Gastrow, 2008). Notably, public research institutes play a significant role in biotechnology research, which makes sense considering the substantial public benefits of biotechnology R&D.

In line with the sample size, open source software development is more concentrated in firms than either nanotechnology or biotechnology. Firm expenditure is more than double that of universities, and may be even higher given the measurement challenges facing surveys aiming to measure open source software development.

Table 2: National Expenditure on Research and Development (R'000s) 2005/6

Sector	Nanotechnology	Biotechnology	Open Source Software	TOTAL
Business	140,922	138,407	60,476	339,805
Science Councils	11,130	129,276	6,035	146,441
Higher Education	85,012	176,819	27,723	289,554
Not For Profit	0	0	7,701	7,701
Government	0	9,624	3	9,627
TOTAL	237,064	454,126	101,938	793,128

In keeping with the confidentiality requirements of the survey, individual respondent details may not be released. There is however a wealth of information regarding performers of R&D in these technologies available in the public domain that can complement these data.

In biotechnology South Africa's Science Councils have a substantial expenditure, far greater than in the other two samples. Information about these activities is publicly available (Campbell, 2007; Kruss et al, 2006). Biotechnology R&D is conducted at public research institutes focussed on agriculture, medicine, industrial applications, and mining. Among higher education institutions there are a number of key performers of biotechnology R&D, mostly drawn from the life sciences faculties of the major universities (Gastrow, 2008). In the private sector, applications are more profit-driven than socially driven, often tailored to South African's comparative advantages. (Campbell, 2007). Private firms from a range of industrial sectors are active in biotechnology R&D. For the biotechnology datast, unlike the other samples, R&D Survey administrators approved the release of Standard Industrial Classification (SIC) codes for the firms in the sample. These data tell us about the primary economic activity of these firms. Of the 22 biotechnology R&D performing firms, the largest number of primary revenue SIC codes were in the pharmaceutical sector (8), followed by chemicals (5), manufacture of food and beverages (3), manufacture of wood, paper and pulp (2), and health (2). The remaining data could not be fully divulged for confidentiality reasons, as only a single firm is active in each remaining sector. These data do however indicate the extent to which biotechnology is both multi-disciplinary and horizontal.

For a previous paper on nanotechnology R&D (Gastrow 2009a), the specific research fields characterising South African nanotechnology R&D were further investigated through direct contact with sample organisations by e-mail and telephone[1], as well as through a literature scan and internet search.

[1]This was possible because the author was at that stage conducting fieldwork for the R&D survey.

This revealed that much of South Africa's nanotechnology R&D is directed at the development of catalysts. This is in line with South Africa's comparative advantage in terms of mineral resources, and has been exploited by researchers both within and outside of firms. The 2002 SANi conference identified nanotechnology related to South Africa's mineral resources as the key focus area of nanotechnology in the country, something that may even provide a niche in which South Africa could become a prominent player (Spicer, 2002).

Catalysis and other nanotechnologies have many applications in mineral beneficiation, resulting in improved recovery rates for the mining industry. Also, several of South Africa's minerals have valuable properties at the nano scale: gold and platinum are both highly effective catalysts, which has lucrative applications in the automotive industry as well as mining. Catalytic converters using platinum are one of South Africa's major exports. Gold and platinum also have useful optical properties that are being explored by Mintek, the public research institute for mining (Spicer, 2002). At the nano scale titanium dioxide has properties that allow a current to be generated, and therefore has potential applications for renewable energy. Vanadium dioxide at the nano scale has properties that allow for the reflection of infra-red light at high temperatures and the transmission of this light at low temperatures which has potential applications in the automotive sector (windscreens) and building construction (windows) to keep interiors cooler. Basic research in these areas takes place at universities in South Africa. For example, the University of the Witwatersrand (Wits) undertakes several catalysis research projects, and South Africa's national power utility parastatal (Eskom) funds a centre for electro-catalysis research based at the University of the Western Cape.

The most active research area in South African nanotechnology, and closely related to research into catalysts, is that of carbon nanotubes (CNTs). A government-funded research centre based at Wits undertakes a range of CNT research projects. In this research Wits has collaborated with the University of Stellenbosch, Mintek, and the Tshwane University of Technology. Research into CNTs has also taken place at the University of Limpopo, and the University of Johannesburg.

Projects listed by SANi show that mining firms routinely outsource nanotechnology R&D to universities and public research institutes, particularly the catalyst/CNT research described above. It is thus clear, even before examining collaboration data, that a network of organisations with research interests and research capabilities are co-operating, particularly where their research agendas overlap and they have the opportunity to benefit from skills, funding or infrastructure located in their partner organisations.

However, not all nanotechnology is directed at mining applications. Among higher education institutions and publicly funded laboratories many other applications are pursued, some with commercial intent and some for the potential social benefits. Wits undertakes research into nano scale drug delivery systems (Moodley, 2007). A major public research institute and a university are engaged in collaborative projects investigating the properties of clay containing polymer composites, the properties of polycrystalline solids, and the generation of MnO2 nanoparticles. Two universities in the Western Cape province have collaboratively investigated nanocrystalline silicon thin films. Research projects at publicly funded laboratories include the development of doped zinc oxide nano-rods, nanostructures of Cr2O3, plasma grown nanostructures of vanadium dioxide, and nano-characterisation of single and double graphene-layers deposited on silicon dioxide. At the University of Pretoria research is undertaken into the development of nano-sized structures on the surface of semiconductors, the development of nanocrystals, and applications of nanotechnology in desalination. The University of Zululand has undertaken research into the synthesis of semiconductor nanoparticles based on gold, silver, and selenium.

Research focus areas in the business sector are more closely guarded. However, some information was provided by firms; some is publicly available. In the pharmaceutical sector nanotechnology-based molecules are currently the subject of several clinical trials. In the paper/pulp sector research includes nanopolymers and nanoparticles to reduce the cost of treating effluent water, nanosilica and nanocoatings to improve the properties of paper and board, and nanosensors in trees to improve the management of forests. A large firm has collaborated with the University of Cape Town to develop nano-inks to print low-tech electronic circuits onto paper.

Information regarding open source software development at public research institutes and universities can also be fairly easily accessed through an internet scan (Gastrow, 2009b). The Council for Scientific and Industrial Research (CSIR), a public research institute, has a specialized open source software centre, with projects ranging from software development to information and awareness dissemination of the benefits of open source software among user communities. South Africa's State Information Technology Agency (SITA) should in principle assist government departments with converting to open source software, but data that might quantify this conversion are unavailable. While government may or may not be taking action, it is the non-profit sector that has taken the lead in terms of open source advocacy in South Africa, most notably the Shuttleworth Foundation. This includes an association for Linux programmers, advocacy programmes, as well as a programme for setting up computer facilities in South African schools using open source principles and software.

To take stock: publicly availably information can tell us something about the structure of R&D in these areas, including networks of collaboration involving firms, universities, and public research institutes. The sample and associated expenditure data can tell us something about where this R&D is located and who is performing it. But are these samples engaged in open innovation? To establish this we can look at collaboration data. But first some caveats: not all of the firms in the samples spend all of their resources on the technologies in question. For example, mining firms might spend a small proportion of their (large) R&D budgets on nanotechnology and biotechnology. When these firms respond to the collaboration question in the R&D Survey, the collaborations in question may in fact be in areas other than these technologies. Thus the collaboration data below must be seen in the light of 1) other available information about collaboration in these areas and 2) the possibility that there is over-representation. In the case of publicly available information, it is clear that firms, universities, and public science institutes are all active collaborators (Campbell, 2007; SANi, 2006; own interviews). With respect to over-representation, there are two mitigating considerations. Firstly, many of these organisations do in fact conduct the majority of their R&D in these areas. Secondly, even organisational collaboration outside of these technologies points to the existence of open innovation systems, in which one of these technologies is part of a larger business model or organisational strategy that is engaged with collaborative research outside the borders of the organisation - in other words, evidence of insertion into open innovation systems.

Tables three, four, and five reflect collaboration data from the R&D Survey. Only firms were asked to complete this question, and not all firms responded (7 out of 8 nanotechnology firms, all of the biotechnology firms, and 14 of the twenty open source software developers). Nonetheless, this is one of the most interesting data sets in terms of understanding the extent of open innovation systems in each of these technologies.

Table 3: Collaboration among nanotechnology, biotechnology, and open source software R&D performing firms 2005/6.

	Collaboration mode	Nano-technology n=7	Bio-technology n=22	Open Source Software n=14	Total n=40
South African Collaborators	Higher Education	6	15	5	26
	Science Councils	5	9	6	20
	Government	2	7	1	10
	Members of own company	4	8	6	18
	Other companies	7	10	6	23
	NPO	1	2	2	5
International Collaborators	Higher Education	3	7	2	12
	Science Councils	1	3	2	6
	Government	2	5	1	8
	Members of own company	2	5	2	9
	Other companies	3	11	4	18
	NPO	1	1	1	3
No collaboration		0	0	2	2

Table 4: Collaboration among all R&D performing firms 2005/6 (n = 327)

Collaboration mode	South African	Foreign
Higher Education	120	31
Science Councils	82	16
Government	43	14
Members of own company	83	54
Other companies	99	62
NPO	15	4
No collaboration	111	79

Table 5: Collaboration modes among R&D performing firms (as a percentage of sample answering collaboration question)

	Collaboration mode	Nanotechnology n=7	Biotechnology n=22	Open Source Software n=14	Total horizontal technologies n=43	Total National R&D Survey n=327
South Afr can Co aborators	H gher Educat on	85.7%	68.2%	35.7%	60.5%	36.7%
	Sc ence Counc s	71.4%	40.9%	42.9%	46.5%	25.1%
	Government	28.6%	31.8%	7.1%	23.3%	13.1%
	Members of own company	57.1%	36.4%	42.9%	41.9%	25.4%
	Other compan es	100.0%	45.5%	42.9%	53.5%	30.3%
	NPO	14.3%	9.1%	14.3%	11.6%	4.6%
Internat ona Co aborators	H gher Educat on	42.9%	31.8%	14.3%	27.9%	9.5%
	Sc ence Counc s	14.3%	13.6%	14.3%	14.0%	4.9%
	Government	28.6%	22.7%	7.1%	18.6%	4.3%
	Members of own company	28.6%	22.7%	14.3%	20.9%	16.5%
	Other compan es	42.9%	50.0%	28.6%	41.9%	19.0%
	NPO	14.3%	4.5%	7.1%	7.0%	1.2%
	No co aborat on	0.0%	0.0%	14.3%	4.7%	33.1%

Firstly, it is clear that the sample firms are far more collaborative than the average R&D performing firm. In nanotechnology and biotechnology every firm in the sample participated in at least one mode of collaboration. For firms conducting open source software development, two of the fourteen respondents to the question indicated no collaboration. This may be because this is a less multi-disciplinary technology, or because the barriers to entry are lower and firms can act independently. However, for the R&D Survey as a whole, 327 firms answered the collaboration question. Of these, 111 (34%) reported no collaboration. By this simple measure we can establish that the samples are more collaborative than average.

There is also a greater propensity to collaborate with other domestic firms. Among the total R&D Survey sample, 120 of 327 (37%) of firms collaborate with South African universities, compared to 99 (30%) with other domestic firms. However, 100% of nanotechnology R&D performers collaborate with other domestic firms, as do 45% of biotechnology firms and 43% of open source software developers. Open innovation practices also include extensive collaboration *within* firms, expressed here as collaboration with 'members of own company'. This includes collaborative partnerships with subsidiaries, joint ventures, or other branches of large enterprises or multi-national corporations. This kind of organizational arrangement is comparatively common in each of the samples. More than half of the nanotechnology respondents reported within-firm collaboration, as well as approximately a third of biotechnology respondents, and 43% of open source software developers - compared to a quarter of the total R&D Survey respondents.

These collaboration modes extend into global innovation networks. All of the samples collaborate with international partners more often than the overall R&D Survey sample with other firms and within their own firm. Interestingly, half of the biotechnology R&D performers reported collaboration with other foreign firms, highlighting the intensity of international networks in this area.

However, the most common single mode of collaboration at the aggregate level for the three samples is with domestic higher education institutions. While Chesbrough's initial model of open innovation was focused on firms, a more recent research agenda has been developed to examine the role of university-industry linkages in open innovation (Perkmann and Walsh, 2007). Contextual information suggests that South Africa universities are chosen as partners for their capabilities in basic research and their existing intellectual and capital infrastructures. These samples are also part of global innovation networks encompassing foreign universities. All of the samples reported proportionally higher levels of collaboration with foreign universities (43%, 32%, and 14% among the samples and 10% for the overall R&D Survey).

Public research institutes also play important roles in these collaborative networks. Contextual information regarding their involvement in nanotechnology research in clearly reflected in the data. The proportions of biotechnology and open source software R&D performers that collaborate with public research institutes are also both higher than the overall R&D sample, at 41% and 43% respectively. Interestingly, public research institutes from other countries also have a role to play in each of these technologies.

Government agencies and non-profit organizations have a marginal role in collaboration, with the exception of government involvement in biotechnology R&D collaboration (almost a third of the sample collaborated with government). This is in line with contextual information highlighting the numerous public benefits of biotechnology research, and the substantial public investment through public research institutes, university-based research centres, and public agencies created by the National Biotechnology Strategy.

We can also examine the technologies individually, as they each have distinct collaboration profiles. All of the nanotechnology firms collaborate with other South African firms - there are no go-it-alone or closed innovation systems in place, and more than half report within-firm collaboration. Nearly all (6 out of 7) of the firms collaborate with local universities, and 5 out of 6 with local public research institutes. Thus the nanotechnology firms are the most intensely collaborative domestically. Nanotechnology firms are also well networked internationally, with the major partners being foreign firms and universities, although collaboration also takes place with foreign governments, public research institutes, sister companies, and even non-profit organisations. Thus the local network is tied into global innovation networks.

The proceedings of SANi conferences (SANi, 2006) provide information that can help to make sense of this. SANi documents show that, in line with the R&D Survey's collaboration data, many of the reported nanotechnology research projects were collaborative in nature. It is clear that the centre of the largest South African nanotechnology R&D network is a group of collaborators based in Gauteng, which includes Wits, the CSIR, and Mintek. The geographically close North West University is also connected to these institutions, as are a number of large mining firms. There is a second, geographically isolated, smaller network involving the University of Cape Town , the University of the Western Cape, the University of Stellenbosch, and the Cape Peninsula University of Technology.

Biotechnology firms have a somewhat different profile of collaboration. Less than half of the firms collaborated with other domestic firms or within their own company. Rather, the most common collaboration mode was with was domestic universities. This makes sense in light of the sample size and expenditure data, where the largest proportion of R&D expenditure is located at universities (while in nanotechnology and open source software development expenditures are most concentrated in firms). However biotechnology firms are also remarkably collaborative, with all of the sample engaged in at least one mode of collaboration. They are also linked into global innovation networks, most commonly through foreign firms and universities, but also through the other modes of collaboration with foreign governments, public research institutes, sister companies, and non-profit organisations.

Open source software has been described as an exemplar of open innovation (West and Gallagher, 2006b). However, these data indicate that this area is in fact somewhat less collaborative than the other two samples (although still far more collaborative than the overall R&D Survey sample). Two of the fourteen firms reported no collaboration, indicating that closed innovation systems are both possible and in place. Also, those that do collaborate do so through fewer types of partners than the other samples. However, the majority of firms do collaborate, with equal numbers partnering with domestic firms, public research institutes, and sister firms, and slightly fewer with universities. Interestingly, while the majority of nanotechnology and biotechnology firms collaborate with local universities, less than half (35.7%) of the open source software firms do so. Nanotechnology and biotechnology require high levels of inputs in terms of basic research, expensive laboratory equipment and skills that reside at universities, and it therefore makes sense to encourage partnerships with universities. Open source software development requires less expensive equipment and less basic research, and software development skills can be obtained through labour markets independently of universities.

However, like nanotechnology and biotechnology, open source software development is linked with global innovation networks, most commonly through foreign firms, but also through all the other modes of collaboration. Public policy does not currently encourage the formation of global innovation networks, or draw upon the potential knowledge pools that these networks represent. This represents a key shortfall in current public policy related to each of the three technologies.

Contextual data have suggested that these collaboration clusters are also geographically clustered, and collaboration data can help build on this information. Tables seven and eight below illustrate the geographical location of the sample.

Table 6: Geographical location of R&D performing organisations 2005/6 (summary)[2]

	TOTAL			
	Nano	**Bio**	**OSS**	**SUM TOTAL**
Eastern Cape	2	2	1	5
Free state	3	2	1	6
Gauteng	13	16	22	51
KwaZulu Natal	2	4	2	8
Limpopo	1			1
Mpumalanga		1		1
Northern Cape		x		1
North West	1	2	1	3
Western Cape	2	8	11	21
Split location		14		14
TOTAL	24	50	38	112

[2] The biotechnology data obtained from the survey included a category of 'split location' where organisations did not have a clear majority of R&D expenditure in any particular province. Organisations conducting nanotechnology and open source software R&D were allocated to the province where the largest proportion of their R&D was conducted.

Table 7: Geographical location of R&D performing organisations 2005/6 (by sector)

	Business				Higher education				Sc ence Counc s	Govern-ment	NPO
	Nano	Bio	OSS	TOTAL	Nano	Bio	OSS	TOTAL	TOTAL	TOTAL	TOTAL
Eastern Cape	1				2	2	1	5			
Free state	6			1	2	2	1	5			
Gauteng		8	17	31	4	6	4	14			
KwaZu u-Nata		1	1	2	2	3	1	6	4	2	
L mpopo					1			1			
Mpuma anga		1		1							
Northern Cape										1	
North West		1		1	1	1		2			
Western Cape		4	8	12	2	3	2	7		1	
Sp t ocat on		6		6		1		1	6	1	1
TOTALS	7	22	26	55	14	18	9	41	10	5	1

These data correspond well with previously indicated structures. Nanotechnology firms are all in a cluster in Gauteng and the Free State. The Free State-based firm is affiliated to the North-West University campus of Potchefstroom, which is geographically near the Gauteng border. This underscores the focus on mining applications when commercializing nanotechnologies. Biotechnology firms are more geographically spread out, with several having split locations in more than two provinces, and a presence in six of the nine provinces. Nonetheless, the largest concentrations of firms are not surprisingly in Gauteng and the Western Cape, where the largest proportions of overall economic activity are located. Open source software firms are also clustered in Gauteng and the Western Cape, with almost no activity outside these centres. Thus for all three samples the areas outside these provinces are play a very small role in overall R&D and appear to be largely excluded from both R&D collaboration clusters and the related geographical clusters.

Higher education organisations are more geographically spread. Since even the smaller universities in rural provinces report some level of R&D in these areas, there is greater geographical spread using this indicator. Unsurprisingly, the public research institutes and government agencies are based in Gauteng or split among national centres.

Thus particular geographical clusters can be associated with R&D collaboration clusters: highly networked firms, public research institutes and universities collaborate in two largely separate clusters of activity based in Gauteng and the Western Cape. This raises questions that are not currently addressed in public policy documents: whether to build upon agglomeration economies by explicitly focusing on technology clusters in Gauteng and the Western Cape, or whether to encourage technology diffusion by supporting small collaborative research activities that extend beyond these clusters.

6. CONCLUSIONS

By drawing together the various data sources at our disposal we can develop a new picture of open innovation in the three focus areas. These findings suggest some directions for policy-oriented research that can help to achieve the potential that these technologies have for future economic growth and social development. A more detailed understanding of open innovation in these sectors, and indeed in the broader economy, could lead to more focused policies that, rather than being generic and using a shotgun approach, are instead aligned with the revealed structures and dynamics of open innovation systems. Policies should take into account critical factors such as: who is controlling research agendas and funding and why, where research is conducted in terms of institutions, sectors and geographical locations, what the intellectual and capital requirements of research activities are, and what the patterns and drivers of collaboration are. Understanding which modes of collaboration are in place and what the resultant network structures look like is critical to designing appropriate policy that can offer optimized support for innovation.

Policies should take into account how the idiosyncrasies of particular technologies impact on all of the above. The role of barriers to entry (intellectual, financial, and institutional) influence how collaboration patterns develop and where R&D expenditure is focused. The potential of technologies to contribute to social development influences public spending patterns. Large firms can control public R&D agendas when it suits their interests. Technologies are channeled by comparative advantages, for example the focus in nanotechnology on catalysts and carbon nanotubes.

Public policies in South Africa also require improved data gathering to inform monitoring and evaluation. This is one way of tracking and ultimately preventing occurrences of government failure to implement policy - for example South Africa's open source software policy. Further research could also develop informative comparisons to other developing countries, particularly those that also have dedicated policies affecting R&D and collaboration in these technologies.

All three technologies in question are highly networked, each reporting proportionally far more collaboration modes than the overall R&D survey data (although open source software is less intensively networked than biotechnology and nanotechnology R&D). All three technologies have a greater propensity to collaborate with other firms, collaborate within firms, and collaborate with higher education institutions. All three technologies are engaged in global innovation networks through multiple modes of collaboration that link local networks with global networks. However, public policy does not provide sufficient support for the formation of global innovation networks in these technologies, and therefore does not sufficiently draw on the enormous pools of capacities and capabilities that these networks represent.

Each of the focus areas also has unique characteristics. For example, in biotechnology the largest proportion of R&D expenditure is reported by universities, while for nanotechnology and open source software development expenditure is concentrated in firms. Also, unlike nanotechnology and open source software development, public research institutes account for a substantial proportion of biotechnology R&D, in line with the significant public benefit and social utility of this research. However, in all three technologies, public policy currently falls short in terms of encouraging networks between public and private sector actors. Given the extensive and advanced capabilities embodied in South Africa firms, policy that encouraged private sector collaboration on public benefit research would harness these valuable knowledge assets.

Spending patterns may also be influenced by the particular requirements of the technologies in question. For example, open source software development has low barriers to entry, and does not always require the intellectual and infrastructural capital resident in higher education institutions. This allows small firms to operate independently from universities by accessing skills and capital through the markets; R&D expenditure in this area is thus concentrated in firms. This raises an additional policy imperative: to support start-ups and small businesses that aim to use the generation of new knowledge in these strategic technologies to foster enterprise development.

In nanotechnology the evidence suggests two major clusters of activity: one based in Gauteng and one based in the Western Cape. The Gauteng cluster includes major mining firms and local universities and public research institutes with a mining-oriented research agenda focused on catalysts and carbon nanotubes. Another network is based in the Western Cape's higher education institutions. These networks are not entirely isolated from each other: they share some common research projects, and both domestic innovation networks are connected to global innovation networks through multiple modes of collaboration.

Overall, these findings highlight that the chosen three horizontal technologies are all highly networked and highly collaborative. However, it is also apparent that current public policies do not take sufficient advantage of this. Public support for network-building in these sectors is minimal. Public funds account for a significant proportion of biotechnology R&D, but falls short in Nanotechnology and Open Source Software development. Nanotechnology has the potential to meet a core public policy objective: the beneficiation of South Africa's natural resources. Policy that encourages open innovation to achieve this objective would be a step forward. Public policy with regards to Open Source Software has been ineffective. In contrast to public statements and public policy, Open Source Software has not been adopted as a government software platform. This shortcoming presents a major opportunity for improvement: funding collaborative open source software development for public purpose would have a substantial fiscal and capability-building benefit.

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