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Conference Paper

Nanotechnology, Industry Competitiveness and University Strategies: the Case of the UWS Nanotechnology Network in South-West Sydney

46th Congress of the European Regional Science Association: "Enlargement, Southern Europe and the Mediterranean", August 30th - September 3rd, 2006, Volos, Greece

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Martinez-Fernandez, M-Cristina; Leever, Kim (2006) : Nanotechnology, Industry Competitiveness and University Strategies: the Case of the UWS Nanotechnology Network in South-West Sydney, 46th Congress of the European Regional Science Association: "Enlargement, Southern Europe and the Mediterranean", August 30th - September 3rd, 2006, Volos, Greece, European Regional Science Association (ERSA), Louvain-la-Neuve

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**SUBMISSION TO 46TH CONGRESS OF THE EUROPEAN
REGIONAL SCIENCES ASSOCIATION**

**Nanotechnology, Industry Competitiveness and University Strategies:
The Case of the UWS¹ Nanotechnology Network in South-West Sydney**

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Abstract

The importance of nanotechnology for manufacturing industries is that it is becoming a transformative element for this sector into the knowledge economy. Access to relevant knowledge is a critical factor in this transformation, as manufacturing firms tend to cluster in peripheral suburbs out of the knowledge intensive ring of central business districts. Results from a project conducted in South-West Sydney from 2003 to 2005 shows that university-industry networking strategies related to nanotechnology raise the awareness of firms to the potential of nanotechnology applications, their willingness to invest in nanotechnology R&D and the number of university-industry cooperation initiatives and business-to-business partnerships.

Keywords: nanotechnology, innovation, manufacturing, Universities, networks.

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1. Introduction

Technological development is one of the factors on innovation and firm competitiveness (Maskell 2001; Smith 2000; OECD 1999) and the absorption of General Purpose Technologies (GPT) is a factor in the continued competitiveness of the firm (Shea, 2005). The impact of nanotechnology in innovation as a frontier technology and a general-purpose technology is only starting to be analysed in detailed. Many firms, from a broad variety of sectors, are unaware of the transformation effect nanotechnology might have in the competitiveness of their business. In this context of early path development of nanotechnology, access to specialised knowledge and to knowledge infrastructure is a critical element for firms to evaluate nanotechnology investments.

The significance of knowledge infrastructure for innovation systems is becoming increasingly acknowledged in the literature. Today, more research than ever is exploring the relationships of creation and diffusion of knowledge, the impact of knowledge and skills, the commercialisation of knowledge, knowledge flows and firm competitiveness, and new enablers of the knowledge society (OECD, 2005; OECD 1999; Maskell 2001; Smith 2000; AEGIS 2005; Audrestsch, 1995; TIAC, 2002; Turpin and Martinez, 2003; Acs, 2002; Martinez-Fernandez et al 2005a). It is now widely recognised that global competitiveness is dependent on the capacity of economies to acquire knowledge capital and to apply new knowledge through a highly trained and specialised workforce.

The role that universities and other knowledge institutions play today in the generation, sharing and transferring of knowledge is being scrutinised by governing bodies of universities and other research organisations (AVCC, 2005; OECD 2005). In addition to training new talent and providing research outputs, 'Third Stream Activities' such as strategic engagement with industry and the community, (Molas-Gallart, 2002) are becoming an important part of universities role in society. Universities are increasingly active in influencing regional competition and recent literature points to a conscious, robust strategy by some universities of driving regional knowledge development (Garlic, 2000; Faulkner & Senker, 1995; Sproats, 2003).

The type of knowledge infrastructure provided by universities is especially significant for countries where the 'tyranny of the distance' means not only external but also internal isolation (Weyman, 2004). Australia is a vast continent with over two-thirds of its land of a remote or rural nature. Population concentrates in a few large metropolitan regions (Brisbane, Sydney, Melbourne, Adelaide and Perth) , as do knowledge institutions. The 'geography of knowledge' shows an unequal landscape where differences are seen at the local level; between suburbs of the east and the west in global cities such as Sydney (Martinez-Fernandez & Rerceretnam, 2006). Access to advanced knowledge becomes an important factor for firm strategy and competitiveness and so are the third stream activities developed by universities.

It is generally agreed today that participation in networks, clusters and alliances proves a powerful learning mechanism for firms, especially if the relationships are in geographical proximity to enable extensive informal knowledge sharing (Martinez-Fernandez, 2004). It has also been discussed elsewhere that regions should maximise the value of their knowledge-generation institutions through linkages with the different actors in their innovation system (Maskell, 2001) to facilitate transfer of knowledge between knowledge providers and specialised industry users (Teece, 1987). University-industry alliances have long been pursued by public funded programs hoping to boost innovation

spillovers in a geographical or cognitive area of research strength of universities. However, there is still a lack of industry-university cooperation in many fields while at the same time the benefits of universities to their regions' knowledge intensity is firmly advocated (Acs 2002, Martinez-Fernandez & Leever 2004, Martinez-Fernandez 2004). The issue is not limited to the dissemination of knowledge, a traditional role of universities, but to introducing change into the region's innovation system through activities that increase industry competitive advantage.

This paper discusses the role of the University of Western Sydney in influencing industry competitiveness and regional innovation through the UWS Nanotechnology Network. A survey conducted among South Western Sydney firms shows that the role of universities in the dissemination and transfer of knowledge of frontier technologies might be bigger than in established technologies. First, nanotechnology as an early path development is discussed, and then the case of the UWS Nanotechnology Network and its role in encouraging manufacturing innovation in South-West Sydney is presented.

2. Nanotechnology & Industry Competitiveness

The global emergence of nanotechnology as the basis of a revolution in industry is rapidly gaining grounds in the literature (ISR, 2001; OECD 2003; Mnyusiwalla et al, 2003; Binks, 2003). Many of its effects are considered as radical innovations with a disruptive impact on firms and a transformative effect in society (Shea, 2005). The early path development of nanotechnology is also being investigated from a social sciences perspective and within the innovation systems analytical framework (Andersen, 2005).

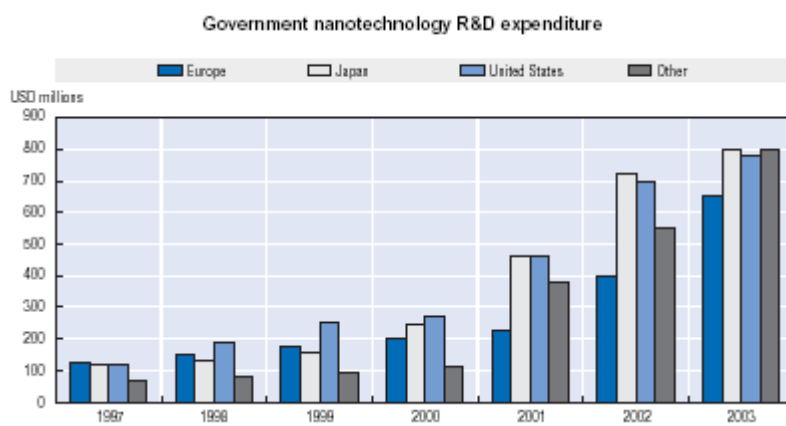
There is not just one definition of 'nanotechnology' although it is agreed that it has to do with the science of the very small. The NASA definition² refers to nanotechnology as a field focused on the creation of functional materials, devices, and systems through the control of matter on the nanometre scale, and the exploitation of novel phenomena and properties at that length scale. The OECD defines nanotechnology as the "range of new technologies that aim to manipulate individual atoms and molecules in order to create new products and processes: computers that fit on the head of a pin or structures that are built from the bottom up, atom by atom" (OECD 2003). Basically, nanotechnology is the design, characterisation, production and application of structures, devices and systems that entails controlling the shape and size at the nanometer scale (Royal Society 2004). The size range of nanotechnology is often delimited to 100 nm down to the molecular level (approximately 0.2nm) because this is where materials have significantly different properties. Nanoscience refers to the scientific analysis of materials at atomic, molecular and macromolecular scales while nanotechnology applies scientific developments to commercialization (Shea, 2005). The field of nanotechnology is incredibly diverse, and many of the applications represent radical innovations in the market, such as an invisible zinc cream, self-cleaning materials, unbreakable fabrics or the development at Queensland University of Technology of cheap, portable, personal solar cells for recharging laptops and mobile phones.

The increase of governments' awareness in the promising economic potential of nanotechnology can be observed in the increase R&D expenditure between 1997 and 2000. R&D funding for nanotechnology grew from USD 114.4 million to more than USD 210.5 million in the European Union and from USD 102.4 million to USD 293

² <http://www.ipt.arc.nasa.gov/nanotechnology.html> last accessed Dec 2005.

million in the US during this period (OECD 2003). The US government invested nearly USD 1 billion into nanotechnology research during 2004, and will add USD 3.7 billion more between 2005 and 2008. Clayton Teague, Director of the US National Nanotechnology Coordinator Office, a government department that facilitates cooperation between academic researchers, corporations and other government offices said at the recent 2004 Boston conference ‘Nanotech’, “the US federal government is committed to the promise of nanotechnology. With all that support, the government and lawmakers are really looking to this field to be a major contributor to our economy over the coming years.” The trend is not unique to the US; countries around the world are increasing their R&D investment in nanotechnology. The figure below shows public investment R&D in nanotechnology since 1997.

Figure 1: Public investment in nanotechnology 1997-2003



Source: National Science Foundation 2003

The US, the EU and Japan are far ahead in R&D investment in nanotechnology since 1997, although other countries such as Italy, Sweden, Finland and France have a high average annual growth rate. According to the US National Nanotechnology Initiative (NNI) worldwide government funding has increased to about five times what it was in 1997, exceeding 2 billion dollar in 2002 (Knop, 2005). The US National Science Foundation has predicted that the market for nanotechnology will reach 1 trillion dollars in 10-15 years (OECD 2004) with an estimated 7 million jobs needed to support the industry worldwide (Knop 2005:8). Venture capital is still small; less than 2 percent of the investments made by venture capital firms in the US in 2003 where in nanotechnology (Lux Research 2004). Analysts consider investments in nanotechnology difficult because the investment landscape is not yet established, there is not much scope for risk diversification and the interdisciplinary, multi-industry nature of nanotechnology means that the investment is not a single, well-defined part of the stock market (Custer, 2005). Large companies with exposure to nanotechnology, companies investing in nanotechnology research and smaller companies with high exposure to nanotechnology seem to be the best options for high-risk investors at the moment (Custer, 2005). The Australian venture-capital sector has show little interest in nanotechnology investments, in part for the reasons outlined above but also because the sector doesn't seem to have the depth of knowledge and confidence to move forward in nanotechnology (BRW 2005:24).

Patents are led by the private sector; the three top patents assignees by 2004 were L'Oreal (266), IBM (125) and Regents of the University of California (107) (Lux Research 2004). Most of the patents are assigned to large multinational corporations³ with a large share of investment in nanotechnology (Shea, 2005). Ten countries (US, Japan, France, UK, Switzerland, Taiwan, Italy, South Korea, Netherlands, Australia) account for almost 90 percent of worldwide nanotechnology patents, the US is leading with over 80 percent and as much as 57 000 patents (Shea, 2005). At the same time there has been an increase in scientific output as measured by the number of scientific publications, which increased from 10 575 in 1997 to 15 667 in 2000. The publication of papers on nanotechnology was largely dominated by the US, Japan and Germany (OECD 2003). A recent bibliographic analysis of nanotechnology citations (Kostoff et al 2006a,b) has found that three Western countries (USA, Germany, France) have about eight percent more nanotechnology publications (for 2004) than the three from the Far Eastern group (China, Japan, South Korea). China, despite the high level of government investment, has minor representation in the most highly cited nanotechnology documents. However, when specific nanotechnologies sub-areas are examined China is leading the USA in articles published (Kostoff et al 2006a). Australia ranks near the bottom in nanotechnology publications and patents (Lux Research 2005).

The impact of nanotechnology in society has been compared to the electronics and computing revolutions of last century. However the path for adopting this new technology at industry level might be retarded if the public is not well informed of the ethical issues that may be involved with nanotechnology. An examination of scientific databases from 1998 to 2001 has shown a paucity of research or discussion on the ethics or social implications of nanotechnology (Mnyusiwalla et al, 2003). This is in some way linked to the lack of research grants awarded on the subject even while governments around the globe have increased interest in the associated social fields to nanotechnology.

The Australian government, for instance, has discussed a workshop on the 'ethics of change' as one of the factors to be considered a primary agenda issue if the rate of nanotechnology diffusion is to be accelerated (ISR 2001). Some of the themes of the ethics of change are issues of equity between developed and developing countries, privacy and security of the public, environmental issues that have not yet been explored, and the important subject of the capacity of nanotechnology to modify living systems (Mnyusiwalla et al, 2003).

Experts also agreed on exploring the full implications of nanotechnology. In a recent article in the Sydney Morning Herald, Dr Peter Binks, Chief Executive of Nanotechnology Victoria concludes: "Nanotechnology is an exciting science, and offers commercial potential and significant benefits to society (Binks 2003). However, society has to assess the full implications of nanotechnology, in terms of its benefits and threats, in order to best capture this potential." Understanding this precautionary approach to nanotechnology is necessary for analysis of firm behaviour to the application of nanotechnology to existing or new products.

Understanding the path creation of nanotechnology requires understanding nano-innovation systems; through the analysis of changes in the organisation of nano-knowledge generation and diffusion, identifying search trends of the nanotechnology community and their emergent strategic research and technology agendas (Andersen,

³ Top ten firms are IBM, Xerox, Micron, Eastman Kodak, Motorola, Texas Instruments, NEC, Canon, Advanced Microdevices, GE.

2005). The application of nanotechnology at the firm level still in very early stages which is understandable as per the complexity of nanotechnology dynamics (see Table 1).

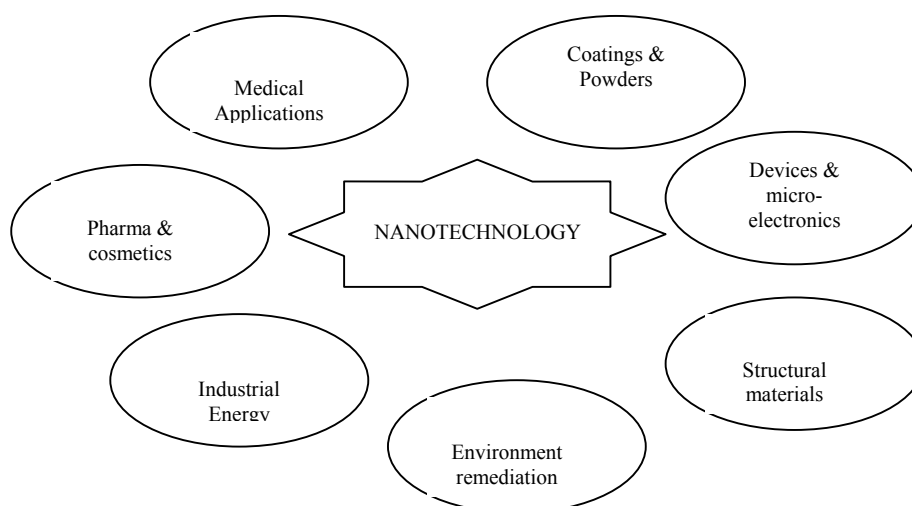
Table 1: Nanotechnology Dynamics

<ul style="list-style-type: none"> • Fuzzy boundaries as it is a technological field not a single technology • Enabling nature as a fundamental General Purpose Technology (GPT) • Unstable base, uncertain industrial applications as the technology is immature • Ubiquitous nature on existing or new materials or converging technologies with multiple functions • Cross disciplinarity of the field, convergence of several natural scientific disciplines • Spectacular nature of the resulting technology. Possible disruptive societal and environmental effects of the technology

Source: Adapted from Andersen 2005, Shea 2005

These dynamics govern emergent nanotechnology activities. Firms are aware of the possible radical or even disruptive effects of nanotechnology and of the implications of its possible transformative effects in society (Shea 2005). As a General Purpose Technology the application to industry sectors is exceptionally varied and requires a different approach to industry analysis as the sectors are blurred and the boundaries are unclear. The use of ‘nanotechnology ecosystems’ might constitute a better term and analytical framework for the study of industry applications of nanotechnology. Within each ecosystem more than one industry coexists, as well as research labs and other organisations. Figure 2 shows seven nanotechnology ecosystems that can be differentiated from the applications so far (Shea 2005, The Royal Society 2004, Wood et al 2003, Luther 2004, Andersen 2005, Lux Research 2004).

Figure 2: Nanotechnology Ecosystems



The industry sectors within each ecosystem are varied, in many cases inter-related and changing at a rapid pace as more discoveries and applications are released in the market. Nano applications also reflect the impact of other technological advances from complementary technologies such as ICT and biotechnology. This strong, changing nature of innovative activity in nanotechnology is both an advantage and a barrier for the firm. For example, disruptive nanotechnology based innovations are more likely to result in decline in economic performance of the firm than non-disruptive innovations (Shea 2005: 196). However, even with the risk involved in disruptive innovation this will eventually improve and become the mainstream technology and those companies ahead of the game will have better bases for sustained competitiveness in the market place.

It is unclear from the literature which mechanisms can be put in place from a policy perspective to assist the transition from emerging technologies to new industries. Firms entering the market either grow and survive or exit the market and at the centre of this process is the complexity of the commercialisation process. The speeding up of the transition from emerging technologies to new industries is central to successful economic growth, employment, competition and sustainability (Hung & Chu 2006). Three policy mechanisms are pointed out by Hung & Chu as means for speeding up this process.

The first is *encouraging partnerships in the commercialisation process* to link discoveries to market opportunities. The second is *fostering entrepreneurship and venture initiatives* in the innovation system to encourage the expansion of entrepreneurial behaviours in the community. The third is *sustaining commercialisation and the creation of new firms*, promoting the survival and growth of those firms that are able to adjust in the market. In the case of Taiwan, these functions are developed as a whole by the Industrial Technology Research Institute (ITRI). ITRI is a non-profit, national research institute that undertakes applied research, produces patents, and transfers its nanotechnology to local industry (Hung & Chu, 2006). One of the activities developed by the ITRI was the 'knowledge-based NanoNetwork' which has a positive effect in improving the domestic nanoresearch environment. A similar initiative, though much more modest, was undertaken by the University of Western Sydney with the formation of the 'UWS Nanotechnology Network' in South-West Sydney. An analysis of this case is presented next.

3. Nanotechnology in Australia: the Case of the UWS Nanotechnology Network in South-West Sydney

Australia is not a leading country in the nanotechnology race. An analysis of 14 countries by Lux Research (2005) shows four different rankings. *Dominant* countries scoring high on both nanotechnology activity and technology development strength are the US, Japan, South Korea and Germany. *Niche players* that score low in nanotechnology activity but high on the technology development strength needed to convert that activity into jobs and GDP are Taiwan, Israel and Singapore. *Ivory Towers* nations, high on nanotechnology activity but low on technology development are the UK and France. And finally the *Minor League*, scoring low on both axes are China, Canada, Australia, Russia and India. Australia has high-profile life science nanotechnology successes but the level of government expenditure in nanotechnology is at the bottom of the rank as well as the number of patents and publications (Lux research 2005).

The Australian nanotechnology ecosystem is very small, characterised by emerging businesses, most of them under capitalised, and a growing academic research capability.

A National Nanotechnology Strategy has been advocated to address specific needs of coordination across all levels of government and to provide a regulatory framework for the sector (PMSEIC, 2005). Recommendation 2 of this Taskforce addresses the need to overcome fragmentation in the sector:

Recommendation 2. That an Australian nanotechnology business alliance be formed with government support whose role is to overcome the current fragmentation evident in the nanotechnology sectors, link business and researchers, and enhance industry application of nanotechnology. (PMSEIC, 2005:5)

Socio-economic analysis of industry applications of nanotechnology is only starting in Australia. A government commissioned report investigating adoption of nanotechnology by Australian businesses found that companies are interested in commercial solutions to problems, not the technology itself. Local companies, in particular, see themselves as users of the technology, rather than developers. Companies also believe there is a clear role for government to support nanotechnology development and adoption through funding research and diffusion of results (Dandolopartners, 2005a).

A survey of 105 businesses investigating investments and attitudes towards nanotechnology (Dandolopartners 2005b) found that 92 percent of respondents were aware of nanotechnology with 40 percent indicating they have detailed knowledge in the subject. Companies appear to be investing in nanotechnology or expect to do so in a significant way in the next five years. 21 percent of companies were already investing in nanotechnology. Companies in the manufacturing sector were the heaviest investors (45%). The size of the firm seems to be important when investing in nanotechnology being the very large (32%) and the small (26%) the bigger investing groups. The majority of businesses do not perceive strong barriers to investing in nanotechnology apart from acquiring the right skills in-house and finding information about products and latest research. Businesses see the main roles of government as providing funding to public institutions for research (66%), encouraging private sector investment in nanotechnology (56%) and providing information to the public about nanotechnology (53%).

At the consumer level, a survey of 1000 people found that Australians are hopeful about nanotechnology, particularly the applications in medical developments, but are concerned about applications in food and consumer products (Dandolopartners, 2005c). This survey also found that Australians place more trust in scientists (75%) to inform them of the risks of nanotechnology than in governments (40%) or business leaders (28%).

Business attitudes towards nanotechnology as outlined in the Dandolopartners' reports contrast with findings of the University of Western Sydney Nanotechnology Network Project⁴. The project ran from 2003 to 2005 and was funded by the Department of Transport and Regional Services (DoTaRS) Sustainable Regions Programme with \$255 000, specifically for the Campbelltown/Camden Local Government Areas in South-West Sydney. The Western Sydney region has the major concentration of manufacturing business in the state of New South Wales (AEGIS, 2005).

The objective of the project was to identify and build nanotechnology business potential in the Campbelltown/Camden Region, specifically in the area of nano-materials. The University aim was to work with existing organisations including local and regional peak industry associations to:

⁴ 'Building Nanotechnology Business Potential in the Campbelltown/Camden Region'

- identify existing enterprises with potential for application of nano-materials technology;
- facilitate and support development of networks and new enterprises applying nano-materials technology; and to
- enable access to funding opportunities for industry and product development with concomitant research and training, including research and development granting schemes.

The project was designed as a ‘Knowledge Intensive Service Activity’ (KISA)⁵ where the UWS Office of Regional Development would organise activities providing specific knowledge, specialised information and opportunities to discuss nanotechnology and possible applications to manufacturing processes. The UWS Nanotechnology Network is formed by an informal group of academics, students, industry, business people, government representatives and community groups that meet quarterly to discuss, attend lectures or seminars and showcase products. Attendance is around 50 people at each meeting. The UWS Nanotechnology Network has a part-time facilitator that compiles a newsletter, maintains the mailing list with over 300 members and the website.⁶ Networking at the quarterly meetings is carefully planned with quality catering and preparation to provide opportunities for people to meet and discuss in an informal setting. The mix of private, public and community sector is also strategically planned so as to facilitate emergence of partnerships.

To ensure the project positively contributed to the region there was a strong emphasis placed upon identifying and evaluating the opportunities that arise from the network activities and the soft infrastructure developed. There was also the consideration that if this particular model of university/industry collaboration proved to be successful the initiative could be expanded or replicated in other regions. As this is a new initiative in an emerging science field there is also the opportunity to evaluate the development of the enterprises, the relationship between the university and industry, and the effects of the project focus on the broader community of the region.

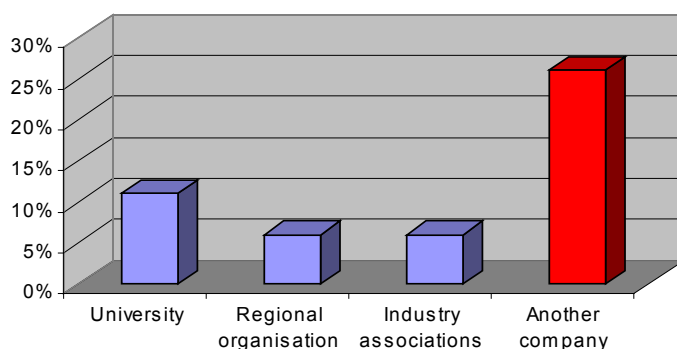
The industry responses to the UWS Nanotechnology Network and its effects were measured via two small surveys in 2003 and 2005 and three in-depth case studies in 2005. The industry break up in the 2003 survey of the network (279 members) shows that the majority of business are in manufacturing (32%), followed by business services (19%), government (17%), university and research and education organisations (29%) and other businesses in the area of biotechnology, ICT, health or packaging (3%). Of the 33 responses of the 2003 survey, only 27 percent of these firms new about nanotechnology and only 6 percent were using nanotechnology. Six percent had plans to introduce nanotechnology, 24 percent were in partnership with a university conducting a particular project and 42 percent of the firms wanted to network with other members of the network.

⁵ Knowledge-Intensive Service Activities (KISA) are defined as production and integration of service activities undertaken by firms in manufacturing or service sectors, in combination with manufactured outputs or as stand-alone services. KISA can be provided by private enterprises or public sector organisations. Typical examples include: R&D services, management consulting, IT services, human resource management services, legal services such as IP-related issues, accounting and financing services, and marketing services. (Martinez-Fernandez et al, 2005b,c,d).

⁶ <http://www.uws.edu.au/nano>

Of the 38 responses to the 2005 survey, 46 percent has participated regularly in the network activities and 51 percent had gained significant new knowledge as a result of their participation. Of the respondents, 26 percent had plans to introduce nanotechnology into their companies and 14 percent had already invested funds on nanotechnology R&D. Up to 26 percent of the companies have initiated new partnerships during their participation in the network. These partnerships were significantly more frequent with other companies rather than with universities, regional organisations or industry associations (see Figure 3).

Figure 3: Partnerships for Nanotechnology Development/Applications



Source: UWS ORD Nanotechnology Survey (2005)

Although partnerships appear to be more frequent among companies than with universities or other public or non-for-profit organisations, universities and research and technology organisations are top providers of knowledge and information for nanotechnology (see Table 2).

Table 2: Sources of Nanotechnology Knowledge (No firms; n=38)

Sources of Knowledge	Not relevant/small importance	Medium/Great Importance
UWS	8	20
Other Universities	10	14
RTOs	10	13
Internet, databases	8	17
Business networks	9	15
Suppliers	12	13
DSRD	11	12
Customers	13	11
Industry associations	14	10
Within the firm	16	8
Other firms within same industry group	15	8
Competitors	16	7
KIBS	16	8
Conferences, journals	16	8
Fairs & exhibitions	16	7

Source: UWS ORD, Nanotechnology survey 2005

These findings contrast with previous research on established technologies. Established technologies such as ICT and software rely more in knowledge produced by their network of contacts: customers, competitors, and conferences. The role of universities as providers of knowledge is very small (see Table 3).

Table 3: Important sources of knowledge for software firms

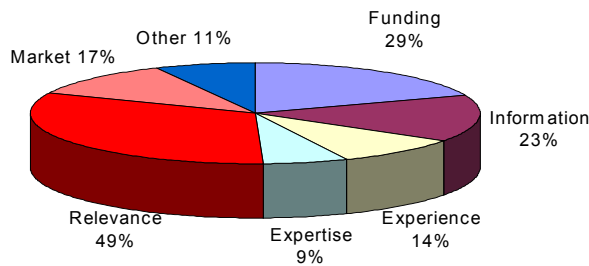
Sources	No of firms (n=54)
Within the firm	47
Customers	47
Databased information networks (Internet)	32
Competitors	22
Conferences, meetings or periodicals	20
Other firms within the same industrial group	17
Suppliers of equipment, material or components	17
Fairs and exhibitions	15
Industry associations	9
Universities and colleges	6
Public/private non-profit research centers	6
Consultancy firms	5
Public patent documents	2

Source: AEGIS KISA Software Online Survey (2003)

Companies applying frontier technologies seem to rely more in scientific knowledge produced by universities and public/private research institutions (RTOs). In-house knowledge has small relevance for frontier technologies but is the greatest source of knowledge for established technologies (Martinez-Fernandez et al, 2005b). Consultancy firms (KIBS), industry associations and government departments have only a small role in the co-production of knowledge in both cases. The survey of South-West Sydney firms found that firms applying nanotechnology were more reluctant to trust in-house sources of knowledge and information while in the case of software, tourism or mining technology services internal sources of knowledge were more important for the firm (Martinez-Fernandez et al, 2005b,c,d; Martinez-Fernandez & Leever, 2004). This difference might relate to the early path creation of nanotechnology if compared with more established technologies.

An interesting result of the survey is that the perceived barriers for the introduction of nanotechnology in the firm's product development have more to do with issues of 'relevance and information' than with the market or the expertise (see Figure 4).

Figure 4: Perceived barriers to the introduction of nanotechnology



Source: UWS ORD, Nanotechnology survey 2005

While funding is seen as a barrier to the introduction of nanotechnology by 29 percent of the respondents, issues of relevance for the firm and of information seen to be far more important (72% of respondents). The success of network approaches by the UWS dissemination of nanotechnology information is addressing this point because companies are able to have a quality well planned context where they are confident to discuss nanotechnology with other interested parties and they are also able to see applications by others and new prospects and are exposed to discoveries by university researchers. The case studies further confirmed this argument.

4.1 Case Studies

Three of the UWS Nanotechnology Network companies from the Campbelltown-Camden area of South-West Sydney were selected for in-depth case studies. The analysis focused on the firm's innovative activity, the type of nanotechnology knowledge intensive service activities (KISA) undertaken and the transforming internal processes used by the firm for the adoption of nanotechnology.

R.J. Walsh & Son Ltd is a 45 year old company which main product are animal powered vehicles. The company has 8 staff, approximately AU\$ 1 million annual revenue and is currently in expansion. The company is characterised by incremental innovations (products/services and organisational). Recently the company has introduced 'Nanoflex', a new steel that is stronger but lighter which constitute an incremental change to the materials used before in their sulkies. Nanoflex enables lighter products of equivalent strength therefore influencing harness racing and dog carting buggy development because they are easier to lift and move. A lighter dog-carting buggy is especially important because 80 percent of this market is composed of women. So far the barriers the company has encountered when innovating are the legislative burden in Australia for introduction of the modified buggy and the lack of information or collaboration related for the application of Nanoflex to its buggies. The most significant barrier has been access to the material itself and the patent which has delayed production for about 18 months.

Knowledge intensive service activities associated with nanotechnology are not very frequent; most of them are undertaken in-house, with other consulting businesses or with UWS, industry associations and government departments. Financing the technology has

been an issue, with the owner investing 10 percent of his time on related nanotechnology R&D. The participation in the UWS Nanotechnology Network has provided a reference point for assistance and also has facilitated the introduction to other companies and their products. The company considered it important to link to UWS for their innovation processes because of UWS's diffusion of knowledge of new technologies and facilitation of meetings with other companies looking for similar solutions.

In relation to how nanotechnology is transforming the internal processes of the firm, this is happening in small, opportunistic and informal bases and mostly led by the owner of the business. One constrain is lack of expertise so at least one engineer with nanotechnology knowledge will be needed for further developments. Collaboration partners in the innovation process are found locally, in a radius of 20 kilometres, especially with UWS, suppliers and clients.

Broens Industries is a 25-year-old company specialising in technology development and special purpose machinery to be used in the automotive, aerospace and biotechnology industries. The company has 132 fulltime employees, currently in expansion and with total annual revenue of more than AU\$ 25 million. The innovative activity of the firm is regarded as incremental at the product/service and organisational level. Latest innovations for the Australian market are new machines for the aerospace and automotive industries. Barriers to innovation were mainly the cost or availability of finance and the changing currency conditions. The management of cash flow is difficult when venture capital is scarce and there is not much government assistance leaving limited margins for investment in technology developments.

The use of nanotechnology KISA is limited to research & product development with other businesses and UWS. The application of nanotechnology is also limited and will be guided by client demand. The investment in nanotechnology is small at the moment, mostly in-kind by the owner, as it is hard to see the short-term benefits. The company is participating with 3 other companies and UWS on a proposal for a technology roadmapping project on toolmaking to improve understanding of the market and focus areas for a more comprehensive applied research project.

The transforming internal processes are patents, seminars and meetings between different sections and a continuous training, mostly customer driven. There is also a mix of people working together; for example a group of designers or engineers work together with a group of tradespeople to work out ideas. As the firm thinks innovation is necessary to survive, it must be commercialised, so these teams are very focused on product development and manufacturing. The firm will need at least one person (part-time) with nanotechnology specific knowledge for the future. Collaboration partners are all from the local area, within 20 kilometres.

KIRK Group is a 32-year-old firm specialising in high resolution printing for corporate plans. The firm has 90 staff members, the business structure is in expansion and the annual revenue is more than AU\$ 2 million. The types of innovations are mostly incremental (product/service and organisational) but they also have a radical process innovation when they standardised international brand colours circular plates for their printing cylinders.

The use of nanotechnology KISA is small and limited to industry development, business planning advice and information sharing and new knowledge. These activities are mainly performed in-house, with other businesses and UWS. They have also gained access to government funding for nanotechnology R&D through an Australian Research Council Linkage grant with UWS. This project provides for the development of the technology needed by the firm and it will constitute a radical innovation. Transforming internal processes are through project folders that can be consulted by all employees, feedback from employees on particular aspects of the project and from allocating current staff to new projects. In the case of the nanotechnology being developed with UWS, current staff will move into the new technology instead of hiring new specialised people. The critical aspect is that technology moves too fast and the time in getting the technology (sooner better than later) is an important competitive advantage. Collaboration partners are found in the local area within 20 kilometres.

The surveys conducted on the UWS Nanotechnology Network over a 2 year period suggest that scientific knowledge is driving nanotechnology agendas and that knowledge intensive service activities facilitated by local universities might have a high impact on firms' competitiveness as universities are partners in co-production of innovation. It also suggests that suburbs/regions with manufacturing business have the potential to apply nanotechnology in the medium term as nanotechnology greatly applies to many manufacturing processes related to fabrics, cosmetics, coatings, metals etc.

The project also shows that nanotechnology research and industry engagement is fragmented in South-West Sydney; the focus of research specialisation and KISA in certain sectors such as plastics, electronics, nanomaterials, nanomedicine, and medical technologies offer good prospects for the future, especially with a new centre for nuclear magnetic resonance (NMR) to be opened at the UWS Campbelltown Campus in mid 2006.

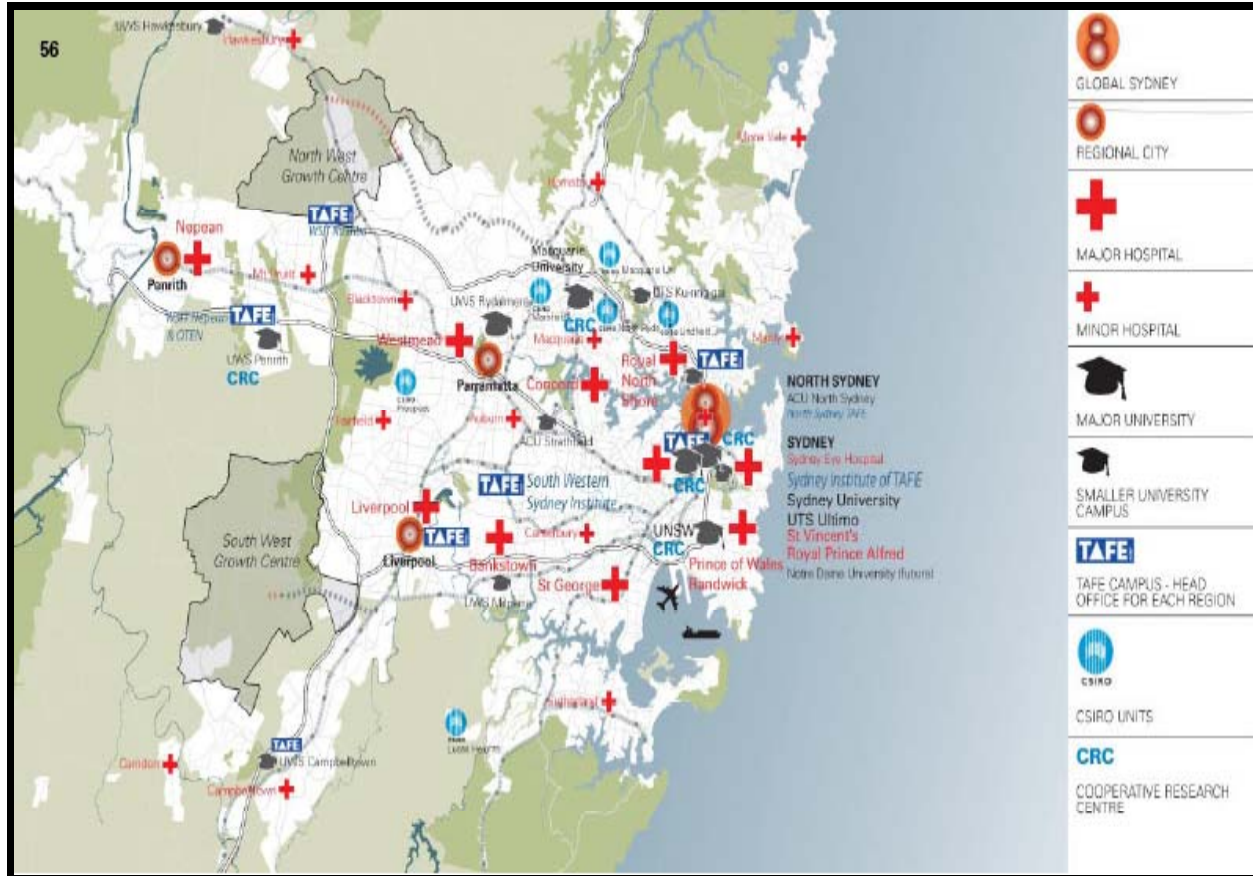
The case studies show that *partners in the innovation process of nanotechnology are from the local area* therefore policies and programs to develop networked nanotechnology innovation systems need to also have a focus at the regional and local level. Local networking strategies and especially those linking industry and university research departments are needed to advance the field in the medium to long term in a way that is relevant for industry.

4.2 Knowledge Infrastructure in South-West Sydney

A further question relates to industry access to knowledge infrastructure in the areas covered by the UWS Nanotechnology Network and whether the geography of knowledge matters. An analysis of the state of New South Wales shows two bands of knowledge institutions. The first along the coast, and the second in the regional areas to the west of the first band. No institutions are located in the far west of the state (the furthest west are CSIRO labs in Griffith). Within the coastal band, there is an obvious concentration bordered by Newcastle, Wollongong, Penrith and the coastline. This can be called the 'Sydney Knowledge Corridor' stretching from Newcastle region to Wollongong with a polycentricity around Newcastle, Sydney and Wollongong (AEGIS, 2005). There are clear concentrations of knowledge producing institutions within this knowledge corridor and the concentrations are in the eastern and central suburbs of Sydney and in Ryde (see

Fig 5). These are also areas of high concentration in terms of the number of ICT and KIBS companies⁷.

Figure 5: Sydney's Knowledge Hub locations in Sydney



Source: NSW Government, Sydney Metropolitan Strategy, Economy and Employment, 2005, p20

Few knowledge institutions are located in the western section of the corridor at any of the city centres. The University of Western Sydney (UWS) has its central campuses west of Homebush, the University of Sydney has a campus at Camden and there is a concentration of research and teaching at and around Westmead Children's Hospital but west of the Ryde-Homebush line there are no CSIRO units. UWS is the only large tertiary level teaching university operating in the western part of the knowledge corridor. UWS serves a very large urban population as well as the rural fringes of the city such as the Blue Mountains, Wollondilly Shire and the Southern Highlands. While this area also supplies other Sydney universities with many students, UWS remains the closest for many and the tertiary institution of their choice.

In most cases, therefore, businesses both in the west of the State and in the west of Sydney do not have the same access to knowledge intensive institutions as those located further east. The far northern suburbs of Sydney are also somewhat disadvantaged in terms of access, in contrast to the south where there is almost equal access to institutions

⁷ Research data from AEGIS ARC Large project on 'The changing Role of RTOs and KIBS in innovation'

located in Sydney and Wollongong. Some companies located in the South West Sydney rural fringe area of Wollondilly, for example, have more connections with the University of Wollongong than with UWS (Martinez-Fernandez et al, 2005).

The presence of a certain level of knowledge infrastructure does not imply a functional system where knowledge dynamics flow through the different organisations of the region. The analysis of these functions or dynamics is also not easy though several attempts have been made in Australia, especially regarding the role of universities in the generation of knowledge (TIAC 2002, AEGIS, 2005, Martinez-Fernandez 2006). The analysis of transfer and application of knowledge is more difficult to evaluate and requires the use of case studies and longitudinal data not usually collected by national or regional agencies.

Three functions can be identified when analysing the role of universities as agents of knowledge: generation, transmission and transfer of knowledge. The *generation* of new knowledge, whether basic or applied, is of relevance to many industries from manufacturing to services. The impact of this knowledge is not necessarily direct, nor immediate, but it is influential in the economic success of players in the region and beyond. This influence occurs through the sustained innovation that universities might facilitate. In addition, universities may generate applied knowledge that is directly and immediately relevant to local industries. This knowledge flows through *networks of expertise* from the private, public and civic sector. The *transmission* of knowledge takes place through the formal training of students and specific *collaboration processes* under partnership agreements.

University expertise (skilled personnel and high level equipment) present in a region is important in two main ways. Firstly, it serves to ‘capture’ knowledge generated elsewhere. Secondly, it enables the region to participate in creating specialised expertise and developing it further to meet local needs. Thus, local, national and international knowledge is translated by university players and *transferred* into locally useful knowledge for supporting existing industries, generating new industries, informing public policies and meeting other community needs such as health, urban planning, environmental control, education, and aged care.

Universities have an important role to play in all three major functions of knowledge but they are not alone and a strong interdependent relationship between universities and the other knowledge producing and using sectors that contribute to knowledge development is also vital (Tornatzky et al. 2001:3). The presence of universities or evidence of the generation and transmission of knowledge does not necessarily mean that a *transfer* into industry, business and commercial activity is taking place. Well-functioning university-industry transfer requires input from both producers and users of knowledge. Interactions between ‘users’ and producers of knowledge have two functions. They create new knowledge, through implementation of technologies, prototyping, pilot plant trials and other forms of testing, and they generate the critical mass needed for sustained innovation. The simple linear model of knowledge flows as between Public Sector Research (PSR) organisations and companies has long ago been replaced by an interactive model (Kline and Rosenberg 1986).

The analysis of university-industry partnerships have the most to offer to the study of knowledge transfer but the analysis needs to be field or sector specific within a region as ‘knowledge needs’ and firm behaviour might vary depending on industry specialisation

and the level of university research strengths. Regarding the role of universities as an innovation generator Acs (2002) used a large innovation database (USA) to test whether university research labs were important for firm innovation. He found evidence that small firms take greater advantage of knowledge spillovers from universities than large firms, for whom corporate R&D is a more important source of generating and commercialising innovation. Acs found that geographic proximity between universities and corporate laboratories within an area clearly serve as a catalyst to innovative activity for firms of all sizes but especially for small firms.

Therefore the knowledge and innovation literature as well as our research results suggest that *access to knowledge infrastructure and linkages to universities facilitates innovation of local firms*. Results from the case of the UWS Nanotechnology Network also indicate that *universities impact is greater in the case of frontier technologies such as nanotechnology than in the case of established technologies*. It can also be argued that *competitiveness of innovative firms need to be seen within the network of relationship with other parts of the regional innovation system in order to understand firm's access and use of cutting edge technology*.

5. Conclusions

Nanotechnology constitutes a breakthrough in science with the capacity to control matter at the atomic level. Industry applications are vast and diverse as materials can be transformed at a very small scale. The introduction in the market of nanotechnology applications has occurred at a very high speed in many OECD countries and the scientific community is growing in strength and industry relevance. However, nanotechnology dynamics related to fuzzy industry boundaries, immaturity of the technology, cross-disciplinarity of the field and the possible radical or even disruptive effects of nanotechnology complicates the analysis of nano-innovation systems and industry development.

As a General Purpose Technology the application to industry sectors is exceptionally varied and requires a different approach to industry analysis as the sectors are blurred and the boundaries are unclear. The use of 'nanotechnology ecosystems' might constitute a better term and analytical framework for analysis as within each ecosystem more than one industry coexists, as well as research labs and other organisations. Among these nanotechnology ecosystems seven have been identified from the literature: medical applications, coating and powders, devices & micro-electronics, pharmaceuticals & cosmetics, industrial energy, environment remediation and structural materials.

International competitiveness of manufacturing industries within nanotechnology ecosystems will be impacted by implementation of nanotechnology in their innovation processes. However, the awareness and participation of manufacturing companies in the nanotechnology race still very limited worldwide. In particular, Australia figures at the bottom of R&D investment, patents and citation measures.

This paper presented the case of a university led nanotechnology network which has a positive impact on manufacturing firms in a peripheral area of Sydney Metropolitan Region. The paper presented results of two industry surveys and case studies of firms participating in the network. The following conclusions can be extracted:

First, companies applying Frontier Technologies seems to rely more in scientific knowledge produced by Universities and public/private research and technology

institutions (RTOs) than in knowledge generated by the private sector. The survey of South-West Sydney firms found that firms applying nanotechnology were more reluctant to trust in-house sources of knowledge and information while in the case of software, tourism or mining technology services industries, internal sources of knowledge are more important for the firm (Martinez-Fernandez et al, 2005b,c,d; Martinez-Fernandez & Leever, 2004). This difference might relate to the early path creation of nanotechnology if compared with more established technologies. Consultancy firms (KIBS), industry associations and government departments have only a small role in the co-production of knowledge in both cases.

Second, results of the survey indicated that the *perceived barriers for the introduction of nanotechnology in the firm's product development have more to do with issues of 'relevance and information' than with the market or the need for expertise.* While funding is seen as a barrier to the introduction of nanotechnology by 29 percent of the respondents, issues of relevance for the firm and of information seem to be far more important for industry (72% of respondents). The contribution of network approaches such as the UWS Nanotechnology Network relates to the dissemination of nanotechnology information and the provision of a quality, well planned context where to discuss nanotechnology with other interesting parties, showcase current commercialisations and discuss new business prospects and discoveries by university researchers.

Third, the surveys conducted on the UWS Nanotechnology Network over the 2 year timeframe suggest *that scientific knowledge is driving nanotechnology agendas and that knowledge intensive service activities facilitated by local universities might have a high impact on firms' competitiveness as universities are partners in co-production of innovation.* It also suggests that suburbs/regions with manufacturing business have the potential to apply nanotechnology in the medium term as nanotechnology greatly applies to many manufacturing processes such as materials, cosmetics, coatings, metals etc.

Four, the project also shows that nanotechnology research and industry engagement is fragmented in South-West Sydney. The focus of research specialisation and KISA in certain sectors such as plastics, electronics, nanomaterials, nanomedicine, medical technologies offers good prospects for the future, especially with a new centre for nuclear magnetic resonance (NMR) to be opened at the UWS Campbelltown Campus in mid 2006. The case studies show that *partners in the innovation process of nanotechnology are from the local area* therefore policies and programs to develop networked nanotechnology innovation systems need to also have a focus at the regional and local level. Local networking strategies and especially those linking industry and university research departments are needed to advance the field in the medium to long term in a way that is relevant for these firms.

Five, access to knowledge infrastructure and linkages to universities facilitates innovation of local firms. Universities impact in firm innovation is even greater in the case of frontier technologies such as nanotechnology. *Competitiveness of innovative firms need to be seen in the context of their access to relevant knowledge and network of relationships with other parts of the regional innovation system; not just as a set of productive resources.*

Six, the *location of knowledge institutions does matter for interactions with industry.* For example, in Australia, knowledge institutions are not widely and equally spread across an

administrative unit such as the State but are concentrated within Sydney, leaving some areas of New South Wales with little access. In all three areas of the activities of a knowledge hub – knowledge transmission, generation and transfer – the centre and east of Sydney do the best, hosting a high concentration of knowledge institutions and the most knowledge-intensive businesses. These are also the areas with higher concentration of knowledge workers. Moreover, even within Sydney itself, where the overall concentration occurs, there are many areas with relatively little access, notably the greater west, in spite of the growing population in Western Sydney. This access to knowledge somehow correlates with concentration of occupations linked to the knowledge economy.

Finally, university strategies for knowledge generation, diffusion and transfer matter for the development of our cities and regions. Networking projects that facilitate well planned knowledge intensive service activities for those areas of expertise that are cutting edge, such as nanotechnology, are fundamental for maintaining industry competitiveness in areas of commercial uncertainty. These networks of innovation require public support to be sustainable in the short term and experiences such as the UWS Nanotechnology Network suggest their effectiveness as innovation policy instruments that can bring similar results to other regions. The results of the network are also bidirectional; at the same time that industry benefits from research discoveries and product showcase, research departments benefit from open dialogue with industry in relation to opportunities for commercialization of new technological developments.

This paper has argued the positive role of universities in influencing the absorption and application of frontier technologies to local industry. Frontier technologies are at the edge of knowledge for many firms and understanding the usefulness and relevance of new, radical, and some times disruptive technology is not always possible, especially for SMEs. The different roles of universities in the co-production of knowledge for industry nanotechnology applications and in analysing its effects in society needs further exploration.

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