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Review of international nanotechnology developments and policy concerns

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EXECUTIVE SUMMARY

Nanotechnology is still in an early stage of development and is largely science-driven. There is a growing interest towards nanotechnology as evident from relatively large R&D expenditures and numbers of scientific publication in this field. To assist developing countries in their pursuit of nanotechnology benefits it is important to identify the key issues driving its trajectory globally. This would pertain to ascertaining various policy initiatives undertaken by countries forerunners in nanotechnology, their R&D focus and strategies for harnessing the potential existing within a research domain, organizations active in various application areas of nanotechnology and human resources development in the sector. This would help understand nanotechnology developments in the context of developing countries.

Further, to strengthen nanotechnology capabilities of developing economies it is important to address the issue of industry-R&D interactions. Dynamic partnership between private firms and public research institutions can play an instrumental role in accelerating the development of emerging technologies from idea to market. Partnerships facilitate the transfer of scientific knowledge to real products and may further contribute directly towards global competitiveness of the industry. Further, partnership offer a means to integrate the diverse participants in the innovation system and provide an institutional structure with financial and policy initiatives within which companies, universities, research labs, and research institutes can cooperate to accelerate the development of promising technologies.

With this background, the present report would provide a comprehensive review of global nanotechnology developments. The purpose is to draw out key lessons and issues of relevance for countries in the developing world to acquire capabilities in NT.

The report is divided into two parts. The first part reviews international nanotechnology developments on following fronts: investment trends, human resources, industrial scenario, and policy developments. Nanotechnology developments in the forerunner countries is characterized by, inter alia, increased investment in R&D, development of competitive R&D infrastructure, interdisciplinary education and training system together with development of entrepreneurship, technology transfer and innovation and, contribution to

economic growth. Differences among countries are observed with regard to the research domain, R&D targets and linkages of academic and research centers with the various industrial sectors.

The second part of the report looks at public R&D and private industry partnerships in nanotechnology with an objective of deriving key policy lessons for developing countries. It was observed that global nanotechnology patenting and publications landscape is characterized by increasing collaboration. Both co-patent and co-publication networks were found to be important in strengthening technological capabilities of firms. Further, since the field of nanotechnology cuts across established disciplinary and sectoral boundaries, multiple interaction channels enable companies to gain access to the latest advancements and enhance their performance. Also, companies profit most from collaborating with research institutes and universities having scientific base, both basic and applied. The key lessons that emerged from international developments in public R&D and private industry partnerships are:

- A committed interaction between the public research institutions and private firms is the precondition for accelerating nanotechnology development. This may be attributed to the interdisciplinary character of nanotechnology, the complexity level, uncertainty and associated risks, high cost of instrumentation and the like. Developing countries, where the public research institutions and private firms operate at arms length and innovation is still perceived as a linear process, may face significant challenge in engaging with nanotechnology and harnessing its societal benefits. In this regard there is a need to make universities entrepreneurial, risk-taking and innovative.
- In science driven technology field like nanotechnology a strong R&D base in the government supported research infrastructure is essential for partnerships in nanotechnology. In developing countries investments in universities should create research and development capability and there is a need to link R&D initiatives with the industrial practice.
- The government has played an important role in facilitating public-private interactions to promote nanotechnology in varied ways like, helping in the establishment of technology transfer and industrial liaison offices at universities, technology incubators, science parks and centres of excellence to increase efficiency from public R&D expenditure and diffusion of knowledge; funding of industry consortia to reduce the technical risks of firms; promoting the mechanisms, which can build the linkages between public research institutions; acting as a mediator between

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public research institutions and industry in the innovation processes.

- The gap between the needs of industries and the capabilities of academia needs to be addressed for productive partnerships in nanotechnology. In this regard there is a need to clearly define the guidelines for organizing collaboration projects between private firms and public research institutions.
- International collaboration in nanotechnology, indicated by co-publications and co-patenting trends at the global scale, has witnessed an increase over the years. Given the increasing global interdependences in nanotechnology, developing countries in their pursuit to engage with nanotechnology can benefit by becoming a part of this global network. This would help developing countries to increase their global visibility in frontier cutting edge science and technology besides building their internal research capabilities.

Global trends and perspectives in nanotechnology

The focus of this review is to highlight nanotechnology developments on following fronts: investment trends, human resources, industry scenario, and policy developments.

Nanotechnology research funding

Nanotechnology is getting the attention of both public and private enterprises across the globe. Investment in nanotechnology worldwide has grown rapidly over the last decades. Total global expenditure (public+private) in nanotechnology in 2007 amounted to \$13.8 billion, up from \$8.6 billion in 2004. There has been an increase in public R&D investments in nanotechnology from \$ 6.4 billion in 2006 to an estimated \$ 9.75 billion in 2009. This may be attributed to considerable socio-economic promise offered by nanotechnology¹.

Looking at the public R&D expenditures it is observed that US, Japan, and Germany dominate the current research and development effort in nanotechnology. In recent years Korea has also emerged as a significant player in the global nanotechnology R&D landscape (Figure1.1). The structure of nanotechnology R&D investment by regions suggests a clear difference between countries as depicted in Figure 1.2. A higher private share in R&D investment has been found in the US and Japan when compared with the EU and others.

¹ Roco, M.C. (2007), "The NNI: Past, Present and Future", in Goddard, W.A et al. (ed.) Handbook on Nanoscience, Engineering and Technology, CRC, Taylor and Francis, Boca Raton and London, pp. 3.1-3.26.

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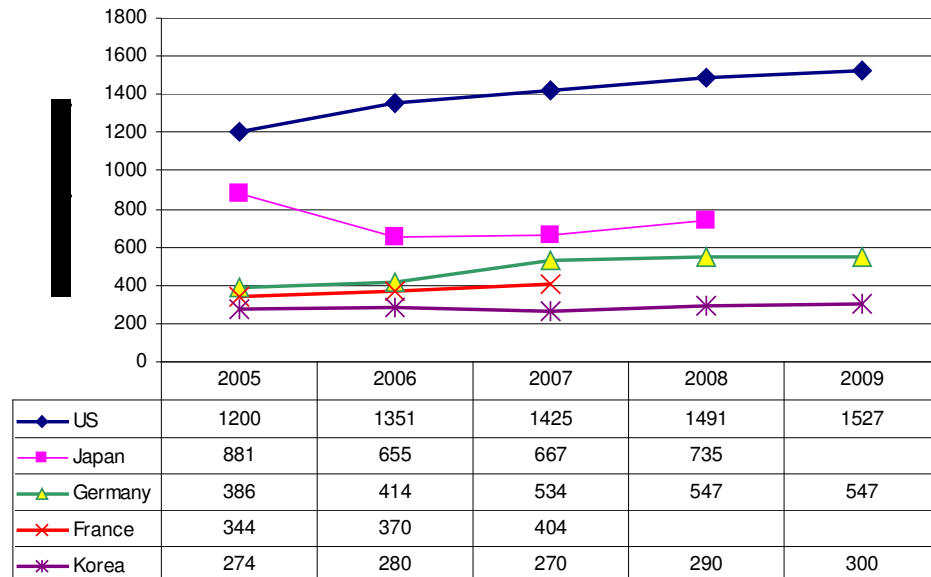


Figure 1.1: Public R&D investments in nanotechnology, 2005-2009¹

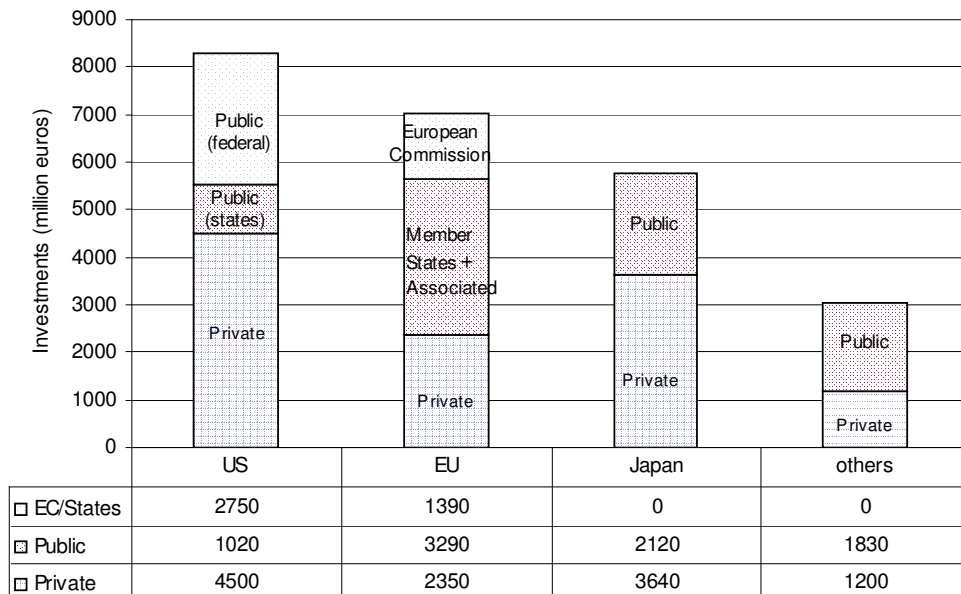


Figure 1.2 R&D investments in the regions by institutional sector, 2004-2006²

Certain trends can be deciphered from the focus areas of government investment in nanotechnology research. The US nanotechnology research spectrum, which is broad encompassing several research areas, have established its strength in synthesis and assembly of nanoscale building blocks and catalysts, and in polymeric and biological approaches to

¹ OECD (2009), "Nanotechnology: An Overview Based on Indicators and Statistics", STI Working Paper 2009/7, Organisation for Economic Co-operation and Development, Paris

² ibid

nanostructured materials. In Japan, research institutes and academic laboratories have made advancements in nanodevices and nano-instrumentation. The European Union provides a diverse combination of university research, networks, and national laboratories with special performance in dispersion and coatings, nanobiotechnology, and nanoprobes. The subsection that follows discusses the research landscape in nanotechnology in the regions of the world: North America, East Asia and European Union.

North America

The US is among the top investors in nanotechnology R&D. There has been an increasing support from the government in the U.S. in nanotechnology basic research, infrastructure development, and technology transfer reflecting the potential of nanotechnology R&D in advancing capabilities and contributing to national priorities. The 2009 budget provides \$1.5 billion for the National Nanotechnology Initiative (NNI) (\$220 million in 2000). Private funding in nanotechnology R&D is more than \$3 billion, which is greater than the federal and state support. Support for defense research programmes in nanotechnology has witnessed a declining trend and funding for nanotechnology-related EHS research has more than doubled, from \$35 million in 2005 to \$76 million in 2009 (~5% of the total investment). Two centres for the Environmental Implications of Nanotechnology have been established in 2008 with the support of \$38 million from the National Science Foundation (NSF) and the Environmental Protection Agency (EPA).

The increased support for nanotechnology R&D in the US has to be seen in the context of the overall research and innovation scenario in the US that has been further strengthened by America Competes Act of 2007, which follows on the American Competitiveness Initiative (ACI) of 2006. The Act focuses on increased support for basic research, particularly in physical science and engineering, and on support for human resources in science and technology.

In the United States, a number of large multinational corporations, small enterprises, and consortia are pursuing nanotechnology-related research and development activities. Small niches in the market as well as support from several U.S. government agencies through the Small Business for Innovative Research (SBIR) program have provided the nuclei for high-tech enterprises. Further, greater private sector participation could be attributed to the fact that venture capital fuels hundreds of start-ups in nanotechnology.

East Asia

Japan is a heavy investor in nanotechnology R&D. However, Japanese R&D investment is not commensurate with the outputs expected from such investments, which could be explained by a number of structural features viz., weak linkages between industry and public research organizations, low level of openness to international trade and investment, little international R&D linkages and, low venture capital investments¹. To overcome the limitations like weak linkages between industry and academia, the Ministry of International Trade and Industry (MITI) – the main government organization sponsoring nanotechnology in Japan – awards projects to universities that encourage use of research professionals from industry. The Japanese government went for a systems reform under the 2nd S&T Basic Plan (2001-06) and removed direct government control from universities making them ‘independent administrative agencies’. This was done with a view to increase autonomy and accountability, introduce greater diversity and allow the best to compete internationally. As a result, there was a spurt in the number of university spin-offs. Also, to promote technology transfer, Technology Licensing Organizations (TLOs) were set up in universities.

Besides government, large companies and private consortia play an important role in nanotechnology R&D in Japan. Small companies play a minor role in this regard. Large corporations’ dominance in research could be attributed to the fact that it is customary on the part of these companies to allocate 10% of sales for research and development.

Japan has research strength in instrumentation development. Research is focused primarily on nanomaterials, for example applications of nanocarbon materials in the field of energy, environment, IT, and biomedical science.

Europe

In Europe, two-thirds of nanotechnology funding comes from governments, the European Commission (EC) and member states, and one-third comes from the private sector. One of the key differences pertaining to nanotechnology R&D between the EU and other forerunner countries in this area (US, Japan) is that R&D in EU is characterized by a range of rapidly evolving programmes and funding sources, largely fragmented, whereas other forerunner countries like, USA have a coordinated R&D programmes in nanotechnology. This is evident from the funding patterns, the EC contributes under its Framework Programme around one-third of the overall European

¹ OECD (2008), Science, Technology and Industry Outlook 2008, Organisation for Economic Co-operation and Development, Paris

expenditure in nanotechnology, while the US allocates over two-thirds of funding as part of the National Nanotechnology Initiative. It would be useful to mention here that in the initial years of nanotechnology developments in the US, the research efforts in nanotechnology was relatively fragmented. This was mainly because research in nanotechnology was developed in open competition with other research topics within various disciplines. Towards this end, an 'interagency coordination group' was established.

For a coordinated and responsible R&D programme in nanotechnology, the EU has outlined and adopted an integrated, safe and responsible approach. The integrated strategy aims to identify and address all factors – research, infrastructure, education, patenting, innovation, safety, and communication – to successfully engage with such emergent technology. The EC developed and adopted in 2008 a code of conduct for nanoscience based on seven principles that cover issues like sustainability, precaution and accountability. It invites member states to take action to promote the safe development and use of nanotechnology among universities, research institutes and companies.

Nanotechnology in industry – companies, products and applications

Nanotechnology commercialization is still at a very early phase. However, the use of nanotechnology in consumer products is growing rapidly and the market for nanotechnology products is predicted to grow at a very rapid rate. According to the research and advisory firm Lux Research the global market for goods based on nanotechnology is predicted to grow from \$147 billion in 2007 to \$3.1 trillion in 2015. Nanoscale materials now are in electronic, cosmetics, automotive and medical products. There are around 1608 nanotechnology companies worldwide at November 2008 according to Nanovip International Nanotechnology Business Directory. The US dominates the global nanotechnology landscape both by the number of companies (Figure 1.3) as well as by the number of nanotechnology-related products (Figure 1.4). The categorisation of nanotechnology products across countries indicates a concentration in the fields of health and fitness products (cosmetics, clothing, personal care and sporting equipment) (Figure 1.4).

According to the recent nanotechnology inventory by the Project on Emerging Technologies at the Woodrow Wilson Centre for Scholars, over 1,000 nanotechnology-enabled products have been made available to consumers around the world. Health and fitness products (cosmetics, clothing, personal care and sporting equipment) constitutes the largest

category of nanotechnology products followed by home and garden, food and beverage, automotive, electronics and computers, multiple uses, appliances and goods for children (Figure 1.5). The analysis of the product category suggests that nanotechnology mainly impacts the consumer goods industries.

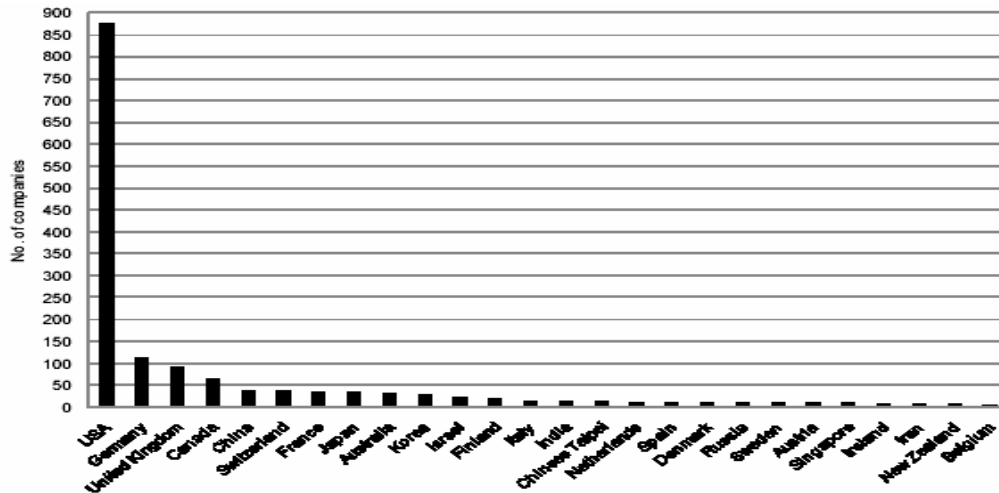


Figure 1.3 Number of nanotechnology companies by country, November 2008¹

Country	Number of products
USA	563
Germany	78
Japan	43
Korea	139
China	56

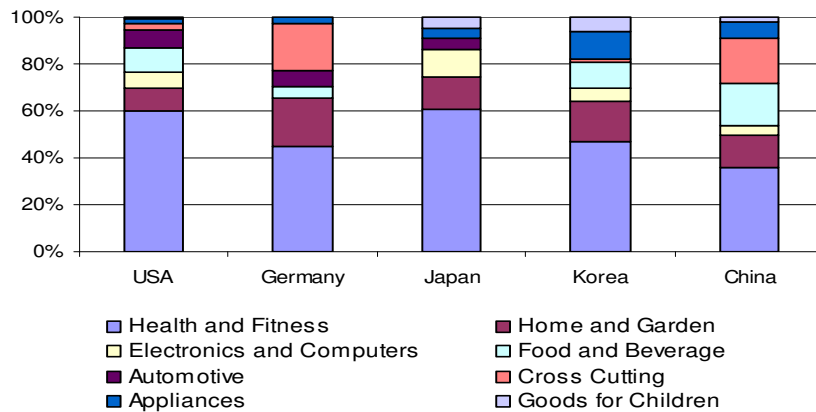


Figure 1.4 Percentage shares of different categories of nanotechnology products by country, October 2009²

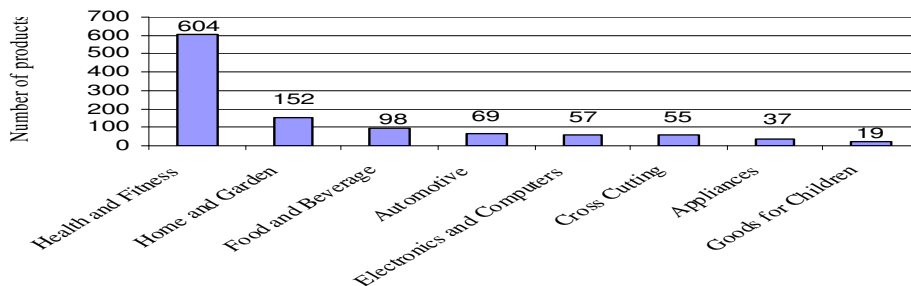


Figure 1.5 Nanotechnology products by main category, October 2009³

¹ www.nanovip.com

² Woodrow Wilson International Center for Scholars (see www.nanotechproject.org)

³ ibid.

Nanotechnology human resources

It has been observed that development in nanotechnology education has not kept pace with the rapidity at which this domain is developing. However, in the recent years education in nanotechnology has shown dynamism in response to the increasing demand for trained personnel in this area. Countries leading in nanotechnology have addressed the need for modification of education system in their respective government documents on nanotechnology, viz., National Nanotechnology Initiative (USA), *Towards a European Strategy for Nanotechnology and Nanosciences and Nanotechnologies: An Action Plan for Europe 2005-2009 (EU)*, the Third Basic Science and Technology Plan (Japan).

Table 1.1 Education and training activities in nanotechnology

Target group	Activities	Remarks
Scientists, staff specialized in technical sciences	Scientific seminars & conferences	<ul style="list-style-type: none"> ▪ Training staff ▪ Exchange of experiences and scientific research results stimulate the future direction of NT development
	Organizing training courses and coordination of training projects	<ul style="list-style-type: none"> ▪ Trends in the US and EU indicates that universities and R&D centers offer diversified educational and training courses in nanotechnology. ▪ The presence of laboratory infrastructures at the nanotechnology centers enables to organize training courses.
Students	<ul style="list-style-type: none"> ▪ Short specialized modules for the graduates on behaviour of materials as an addition to the existing curricula. ▪ Master programme in nanotechnology for graduates already familiar with the behaviour of materials. ▪ 3-4 years programme for the beginners having a very limited knowledge of materials. 	<ul style="list-style-type: none"> ▪ Education in nanotechnology around the world is primarily imparted in the system of post graduate and doctoral studies. ▪ In Japan, education in nanotechnology has been introduced at the primary school level and in Taiwan at the secondary school level.

Developments and initiatives in nanotechnology education

Development of human resources in nanotechnology involves a multi-disciplinary orientation. Accordingly, nations have started offering nanotechnology education at different levels in their education system. The US offers the degree of Master of Science in Nanotechnology and PhD in Nanotechnology and provides Associate Degrees or certificates. A series of interdisciplinary centers with nanotechnology activities has been established at many U.S. universities, creating a growing public research and education infrastructure for this field. As an integrated approach to strengthen European R&D in nanotechnology, the EU proposes to promote the interdisciplinary education and training of research personnel

together with a strong entrepreneurial mindset. The European nanotechnology education landscape is varied with nations offering nanotechnology at Bachelor's, Masters and PhD level. In Japan nanotechnology has been implemented into regular educational system and has been introduced at primary school level.

USA

Nanotechnology education in the US is coordinated by National Nanotechnology Infrastructure Network (NNIN), which consists of 13 US universities. The universities in the NNIN implements education curricula and offers training course in the different disciplines of nanotechnology. A greater cooperation between academia and research centers has been envisaged upon.

Under the NNIN, educational research programmes for students (Research Experience for Undergraduates - REU) as well as curriculum for postgraduate and training programmes for secondary school teachers have been developed (The Research Experience for Teachers - RET)

Japan

For the development of nanotechnology education system in Japan, the Nanotechnology Researchers Network Center of Japan (Ministry of Education, Culture, Sport and Technology) manages the following:

- Summer Nanotechnology School – students learn quantum mechanics, the knowledge of which is necessary to operate electronic and optic nanodevices applied in computer science and communications. Issues dealing with physics of organic semiconductors and the theories of quantum information processing are also introduced. The curriculum encompasses classes in nanomedicine, nanobiology and nanophysics.
- Multidisciplinary school – the main discipline is nanobiotechnology. The classes comprise problems concerning living organisms at molecular level.
- Exchange Program for Young Scientists – the scientific and technical cooperation in the field of nanotechnology is promoted on international arena. Countries involved in this project are the United States, Great Britain, France and Sweden.

Europe

The EU is having a differentiated education in the field of nanotechnology in terms of the number of majors in nanotechnology at the masters and doctoral level. Among the European countries, Great Britain followed by France and Germany plays leading role in having the most differentiated nanotechnology education at the masters and doctoral level.

The education system in Great Britain has been changed recently particularly at the masters and postgraduate level to adapt to the demands posed by nanotechnology. Educational modules in nanotechnology have been introduced in several universities at these levels.

Role of ICT in nanotechnology education

Advanced communication techniques and multimedia to support nanotechnology education has been used in countries leading in nanotechnology. For example, under the NNIN of USA, a complex internet service consisting of an educational portal, training courses, seminars and presentations on nanotechnology can be accessed online. Cornell University's website Nanooze aims at nanotechnology education for children. The website for European forum on nanotechnology, Nanoforum, provides access to recent publications, lectures, training materials, list of academic centers on nanotechnology. Japan's *Nanotechnology Researchers Network Center of Japan (nanonet)* provides information on conferences, seminars, courses and also selected papers published by Japan Nanonet Bulletin – JNNB

Recent policy developments in nanotechnology around the world

In continuation with the earlier research deliverable on review of international nanotechnology developments in which a detailed analysis of various policy initiatives in nanotechnology across the globe was undertaken, this section would provide an update on recent policy developments in nanotechnology in the forerunner countries.

USA

The responsible development of technology is to be accomplished by addressing environmental, health and safety (EHS) concerns, engaging in public education and outreach and other social, ethical and legal issues. To achieve this end, the 2009 budget funding for nanotechnology-related EHS research in NNI has more than doubled (see, Box 1.1). Furthermore, to strengthen the federal efforts to better comprehend the potential EHS concerns of nanotechnology, the House, Science and Technology Committee introduced a new bill, H.R. 554.

Box 1.1: 2009 National Nanotechnology Initiative Investment: Key points

- Increased support for research on fundamental nanoscale phenomena and processes, from \$ 481 million in 2007 to \$ 551 million in 2009.
- Supports nanoscale science and engineering R&D at 13 agencies, with the greatest investments in Department of Defense (DOD – investments addressing the defense mission); the National Science Foundation (NSF – fundamental research across all disciplines of science and engineering); the Department of Energy (DOE – research providing a basis for new and improved energy technologies); the National Institutes of Health (NIH, intersection of biology and the physical sciences); and the National Institute of Standards and Technology

(NIST – fundamental R&D of tools, analytical methodologies, and metrology for nanotechnology).

- There has been increase in NT R&D funding for DOE, NIST, and NSF among others, which reflects the President's commitment to significantly increase funding for physical sciences and engineering research as part of the American Competitiveness Initiative. For gathering inputs and feedbacks from industry and the research community regarding such growing investments a series of workshops are being organized by NNI agencies.
- There has been over the double Environment, Health, and Safety (EHS) R&D funding (from \$ 35 million in 2005 to \$ 76 million in 2009). This follows the NNI strategy for expanding the capacity to do high-quality research in this field.

Source: National Nanotechnology Initiative: FY 2009 Budget & Highlights, National Science and Technology Council, Executive Office of the President of United States. Available at http://www.nano.gov/NNI_FY09_budget_summary.pdf

Japan

The Japanese 3rd Basic S&T Plan (2006-11) in the light of severe fiscal circumstances emphasises selection and concentration in investment compared with the 2nd Basic Plan. It retains the concept of strategic prioritisation in the 2nd Basic Plan and continues to promote basic research and investment in the four prioritised areas – life sciences; information and communications technology; environmental sciences; and nanotechnology and materials science. Under the policy of selection and concentration, the 3rd Basic Plan requires Council for Science and Technology Policy (CSTP) to determine Promotion Strategies including “essential R&D themes”, which indicate preferred budget allocations over the next five years. For each theme, R&D goals to be achieved in the period of the Basic Plan, as well as those to be achieved finally, are required to be shown in the promotion strategies¹ (see, Table 1.2).

Table 1.2 Major themes and goals in nanotechnology under the 3rd Basic S&T Plan (2006-2011)

Prioritized area	Major theme	Goal
Nanotechnology and materials science (10 themes in total)	Materials contributing to cost reduction in clean energy	To develop fuel cell vehicles with a travel distance of 400km and a durability of 3000 hours by 2010
	Materials that overcomes the issue of natural resources exhaustion	To develop technologies alternating the functions of rare substances by around 2015
	Super early diagnosis and minimally-invasive care	To develop diagnosis technology for 1mm cancers by 2011
	X-ray free electron lasers	To realize measurement and analysis with the world shortest wavelength laser by 2011

Source: Extracted from Nikkei Sangyo Shimbun cited in Tanaka, Ryoza, “The Third Science and Technology Basic Plan in Japan”, British Embassy Tokyo, April 2006

¹ Tanaka, R (2006), “The Third Science and Technology Basic Plan in Japan”, British Embassy Tokyo, April 2006

Europe

Based on the areas identified in the 2004 Communication *Towards a European Strategy for Nanotechnology, an Action plan Nanosciences and Nanotechnologies: An Action Plan for Europe 2005-2009* was proposed by the European Commission. Some of the important activities that have been envisaged upon in the Action Plan is provided in Table 1.3.

Table 1.3 Major areas and strategies in NT in the EU

Area	Strategy
Research, development and innovation	<ul style="list-style-type: none"> ▪ Increased funding for NT R&D under FP7 and strengthening of interdisciplinary R&D along the entire chain for knowledge creation, transfer and use. ▪ Support to research in nanoelectronics under the FP7, so as to stimulate industrially relevant research in technologically matured field. ▪ Support for performing collaborative R&D on potential EHS aspects of nanotechnology. ▪ Development of European Technology Platform for implementing a strategic R&D agenda for nanotechnology sectors important for Europe's competitiveness.
Infrastructure	<ul style="list-style-type: none"> ▪ Mapping existing NT infrastructure and exploring ways to maximize the added value by the exchange of best practice; special focus on industry needs particularly that of SMEs ▪ Support cross boundary networking and integration of resources across academia, R&D organizations and industry
Human resources	<ul style="list-style-type: none"> ▪ Networking and dissemination of best practices for education and training in NT ▪ Creation of an 'interdisciplinary European award in nanoscience and nanotechnology' in the area of safety and the environment
Industrial innovation	<ul style="list-style-type: none"> ▪ Exchange of best practices for commercialization by bringing together stakeholders ▪ More industry involvement in collaborative EU R&D projects for NT ▪ Support the establishment of a NT Patent Monitoring System
Societal concerns	<ul style="list-style-type: none"> ▪ Ethical analysis of nanomedicine by the European Group on Ethics in Science and New Technologies ▪ Support studies and foresight activities into future NT scenarios to provide information on risks and its societal impacts ▪ Raising awareness of NT by producing multilingual information material.
Environment, health and safety aspects	<ul style="list-style-type: none"> ▪ Identifying and addressing safety concerns at the earliest stage ▪ Development of terminology, guidelines, models and standards for risk assessment at all stages of the life cycle of NT products ▪ Minimise exposure of workers, consumers and the environment to NT in a safe and cost-effective manner

Source: adapted from 'Nanosciences and Nanotechnologies: An Action Plan for Europe 2005-2009', European Commission, 2005

Concluding observations

A large number of universities and companies are working on nanotechnology across the globe. The research in universities has led to a number of spin-offs covering major fields of application. Companies have also invested heavily in universities actively involved in nanotechnology research and there is a considerable number of industry investments both in collaborative research as well as new product development thereby showing the significance of university-industry relationship.

Nanotechnology is research-intensive and relies on public as well as private R&D funding. To be effective, this funding has to promote a scientific and technological information exchange, while developing a highly skilled human resource base. It also has to be used to combine scientific knowledge from various disciplines in universities and government laboratories, a requirement that presents quite a challenge to more traditional institutions. Public-private partnerships can play an important role in advancing nanotechnology by marrying public sector funding and research capabilities with the private sector. The next chapter of the report looks at public private partnerships in nanotechnology across regions of the world and draws some policy lessons for developing countries.

Public R&D–Private Industry Partnerships in nanotechnology

This part attempts to analyse the dynamics of collaboration between private firms and public research institutions in countries forerunner in the emergent domain of nanotechnology. Particularly, the government's role in facilitating such interactions would be focused upon. The objective is to derive certain policy lessons for developing countries that are characterized by weak or no public-private collaborations.

It is assumed that forging of links between science and industry is an important means of stimulating knowledge development leading to commercial innovation. It is further assumed that there is an interaction deficit in the developing countries, and for innovation in “new” science there is a need to overcome this deficiency. The policy lessons learnt from review of international developments can help in filling up this gap. The chapter is structured as follows. Following the introduction, Section 2 provides an understanding of the concept of PPP. Section 3 characterizes participation in nanotechnology globally with a focus on forerunner countries viz., USA, EU and Japan. In Section 4 the chapter analyses global trends in nanotechnology collaboration. Section 5 provides the conclusion discussing key policy lessons from the perspective of developing countries.

Introduction

Partnerships help to address major challenges and opportunities at the nexus of science, technology and economic growth and thus constitute a critical policy instrument¹. Dynamic partnership between private firms and public research institutions can play an instrumental role in accelerating the development of emerging technologies from idea to market. Partnerships facilitate the transfer of scientific knowledge to real products and may further contribute directly towards global competitiveness of the industry. Further, partnership offer a means to integrate the diverse participants in the innovation system and provide an institutional structure with financial and policy initiatives within which companies,

¹ Wessner, Charles W. (2002), “Government-Industry Partnerships for the Development of New Technologies”, The National Academies Press, Washington DC

universities, research labs, and research institutes can cooperate to accelerate the development of promising technologies.

Partnerships are critical for emerging technologies¹. In young and highly dynamic fields such as nanotechnology, many research breakthroughs are stimulated in the intersection of established scientific disciplines and across fundamental and applied technological research. It is in such fields that new scientific sub-fields emerge, and where considerable potential for technological innovation can be found. Therefore, partnerships are an important dimension of performance in the emerging field of nanotechnology.

Partnerships are diverse in structure, mechanisms, and goals. Mechanisms for successful partnership vary greatly and is affected by differences in geographical and local industrial circumstances, institutional setting, financing mechanisms, policy strategies and the like. Nonetheless, lessons from various initiatives in public-private partnerships world over could have applicability across a wide array of institutional settings and there is great potential for mutual learning from, and interdependence between, technology-related policies in different countries.

There exists a vast array of forms of partnerships between public and private sector. For simplistic convenience, this Chapter would focus on university–industry partnerships in nanotechnology. The reasons for studying university-industry linkages are following. Firstly, in science-based technologies like nanotechnology, universities are the major sites of knowledge production and firms tend to rely highly on universities in the technology development process. Therefore, university-industry linkages form an important characteristic in nanotechnology. Secondly, both university and industry are facing challenges in today's globalized world. Industries in order to stay competitive want to broaden their scientific base. For this they are collaborating with universities and research institutions. Universities on the other hand are under pressure to seek funds from non-government sources. Thus, an efficient collaboration between university and industry becomes important in this respect.

Understanding public private partnership

There is a wide recognition that technology and innovation is key to foster economic growth and competitiveness of nations.

¹ Heinze, T. and Kuhlmann, S. (2008), "Across institutional boundaries? Research collaboration in German public sector nanoscience", *Research Policy* 37, pp. 888-899.

In the new growth theories technological change, knowledge accumulation and its spillover into production process is considered as the primary engine of economic development^{1, 2,3,4,5}. Consequently for a tightly knit relationship between science, technology and economic performance, partnerships and networking among producers and users of knowledge assumes greater significance.

Definition

There is no uniformly accepted definition of partnership in science policy literature. For example, Coburn (1995)⁶ used the term synonymously with cooperation wherein he defined cooperative technology programmes as “public-private initiatives involving government and industry – and often universities – that sponsor the development and the use of technology and improved practices to measurably benefit specific companies.”

Public-private partnership has been explained by the National Research Council⁷ in terms of its role: “Public-private partnerships involving cooperative research and development among industry, government, and universities can play an instrumental role in introducing key new technologies to the market ... [Partnerships] often contribute to national missions in health, energy, the environment and national defense and to the [N]ation’s ability to capitalize on its R&D investments.”

A key distinguishing feature of public-private partnerships is the art of sharing risks and strategies to gain competitive advantages. The appropriate allocation of resources, risk and timelines is always necessary to the success of the partnership. In this regard the Canadian Council for Public-Private Partnerships defines a public-private partnership as “a cooperative venture between the public and private sectors, built on the expertise of each partner, that best meets clearly define public needs through the appropriate allocation of resources, risks and rewards.”⁸

¹ Romer, Paul (1986), "Increasing returns and long run growth." *Journal of Political Economy* 94(5), pp. 1002-1037

² Romer, Paul (1990), "Endogenous technological change." *Journal of Political Economy* 98(5), pp. S71-S102

³ Romer, Paul (1994), "The origins of endogenous growth." *Journal of Economic Perspectives* 8(1), pp. 3-22

⁴ Grossman, Gene and Elhanan Helpman (1991), *Innovation and growth in the global economy*. (Cambridge: MIT Press)

⁵ Grossman, Gene and Elhanan Helpman (1994) .*Endogenous Innovation the Theory of Growth*. *Journal of Economic Perspectives* 8(1): 23-44

⁶ Coburn, C., (1995). *Partnerships: A Compendium of State and Federal Technology Programs*. Battelle Press, Columbus

⁷ Charles W. Wessner (Ed.) (2002). *Government-Industry Partnerships for the Development of New Technologies*, National Research Council; The National Academies Press, Washington, D.C., 2002; 176 pp

⁸ See, www.pppcouncil.ca/aboutppp.htm

Furthermore, technological advancements in the years past, characterized by complexity and interdisciplinarity, have influenced existing organizational arrangements amongst actors giving rise to new forms of configurations. Lawther (2002)¹ in the report on “Contracting for the 21st Century: A Partnership Model”, had tried to capture this aspect by defining public-private partnerships as: “Relationships among government agencies and private or nonprofit contractors that should be formed when dealing with services or products of highest complexity. In comparison to traditional contractor- customer relationships, they require radical changes in the roles played by all partners.”

The definition of partnerships used by the Council on Competitiveness² “... as cooperative arrangements engaging companies, universities, and government agencies and laboratories in various combinations to pool resources in pursuit of a shared R&D objective” had provided guidance to scholars working in this area. According to Link (2006)³, “a public-private partnership is a relationship – either formal or informal among participants in the R&D process, or institutional – that involves the use of public and/or private resources be they financial, infrastructural or research based.” Similarly, Hagedoorn et al. (2000)⁴ defined partnership “... as an innovation-based relationship that involves, at least partly, a significant effort in research and development (R&D).”

Taxonomy of public-private partnerships

Based on the above definition, Hagedoorn characterized partnerships along two mutually exclusive dimensions – members of the relationship, and organizational structure of the relationship. On the basis of the composition of its membership, a research partnership can be classified as public, private, or public-private. Based on the organizational structure, research partnerships can be formal or informal arrangements governing general or specific objectives in research or commercialization and involve two or multiple actors. While informal arrangements exceed formal partnerships, very little is known about the former, as there is not a systematic way to track these partnerships.

¹ Lawther, W.C (2002). Contracting for the 21st Century: A Partnership Model. 2002. Arlington, VA: The Pricewaterhouse Coopers Endowment for The Business of Government. (monograph)

² Council on Competitiveness (1996), Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness Council on Competitiveness, Washington

³ Link, A N (2006), Public/Private Partnerships. Innovation Strategies and Policy Alternatives, XVI, 160 pp

⁴ Hagedoorn, John, A. Link & N. Vonortas, (2000), Research partnerships, Research Policy, 29, pp. 567-586

Public-private partnerships can be classified according to functional objectives and goals of governments such as, support for strategic research and technology development, improving the mechanisms for commercialisation and technology diffusion, generating spin-offs of technology-based firms.

Public-private partnerships can also be characterized on the basis of government involvement as: indirect or direct. In the case of direct government involvement there is an explicit allocation of resources including financial, infrastructural and research (Link, 2006).

There could be other categorical approaches to public-private partnerships. For instance, Coburn (1995) classified public-private partnerships into five functional categories on the basis of benefits and services accrued to industry viz., (1) technology development (research and applications for new and enhanced industrial products and processes), (2) Industrial problem solving (identifying and resolving firm level industrial needs through technology and best-practice applications), (3) technology financing (public capital or help in gaining access to private capital), (4) start-up assistance (aid to new, small technology-based businesses), and (5) teaming (help in forming strategic partnerships and alliances).

A summary of categories of public-private partnerships is provided in Table 2.1.

Table 2.1 Taxonomy of public-private partnerships

Basis of Classification	Taxonomy	
Composition of members (Hagedoorn, 2000)	Public	
	Private	
	Public-Private	
Organizational structure (Hagedoorn, 2000)	Formal	Research corporation (equity joint ventures between at least two firms having focus on R&D)
		Research joint ventures (joint R&D pacts or consortia to cover non-equity arrangements)
	Informal	Undefined arrangement
Government involvement (Link, 2006)	Indirect	-
	Direct	Financial resources
		Infrastructural resources
Benefits and services to industry (Coburn, 1995)	Technology development	
	Industrial problem solving	
	Technology financing	
	Start up assistance	
	Teaming	

Given these characterizations, public-private partnerships assume greatest attention from the perspective of technology

policy since they exemplify government intervention to address the barriers in the innovation process. Accordingly, this Chapter would make an attempt to understand the dynamics of public-private partnerships in different geographical settings with a focus on nanotechnology.

Characterising partnerships in nanotechnology globally – USA, Europe and Japan

The importance of research collaboration in the innovation process is widely acknowledged (Steensma, 1996¹; Ahuja, 2000², Hagedoorn et al., 2000³; Powell et al., 2005⁴) and the literature on institutional interfaces between university and private sector research is widely available (Meyer-Krahmer & Schmoch, 1998⁵; Owen-Smith et al.⁶, 2002; Calvert & Patel, 2003⁷). Further, various studies have addressed the individual and network level of collaborative research (Landry & Amara, 1998⁸; Melin, 2000⁹; Newman, 2004¹⁰; Lee & Bozeman, 2005¹¹) as well as there are studies that demonstrates the growth of international collaboration in science and technology (Narin, 1991¹²; Luukkonen et al., 1992¹, 1993²; Miquel & Okubo, 1994³;

¹ Steensma, H.K. (1996), “Acquiring technological competencies through inter-organizational collaboration: An organizational learning perspective”, *Journal of Engineering and Technology Management* 12 (4), pp. 267–286.

² Ahuja (2000), “Collaboration networks, structural holes, and innovation: a longitudinal study”, *Administrative Science Quarterly* 45 (3) (2000), pp. 425–455.

³ Hagedoorn, J., A.N. Link and N. Vonortas (2000), “Research partnerships”, *Research Policy*, 29, pp. 567–586.

⁴ Powell, W.W., D.R. White, K.W. Koput and J. Owen-Smith (2005), “Network dynamics and field evolution: the growth of interorganizational collaboration in the life sciences”, *American Journal of Sociology* 110 (4), pp. 1132–1205.

⁵ Meyer-Krahmer, F and U. Schmoch (1998), “Science-based technologies: university-industry interaction in four fields”, *Research Policy* 27, pp. 835–851.

⁶ Owen-Smith, J., M. Riccaboni, F. Pammolli and W.W. Powell (2002), “A comparison of U.S. and European university–industry relations in the life sciences”, *Management Science* 48 (1), pp. 24–43.

⁷ Calvert, J., and P. Patel (2003), University–industry research collaborations in the UK: bibliometric trends, *Science and Public Policy* 30 (2) (2003), pp. 85–95.

⁸ Landry, R. and N. Amara (2008), “The impact of transaction costs on the institutional structuration of collaborative academic research”, *Research Policy* 27, pp. 901–913.

⁹ Melin, G (2000), “Pragmatism and self-organization: research collaboration on the individual level”, *Research Policy* 29, pp. 31–40.

¹⁰ Newman, M.E.J. (2004), “Who is the best connected scientist? A study of scientific coauthorship networks”, In: E. Ben-Naim, H. Frauenfelder and Z. Toroczkai, Editors, *Complex Networks*, Springer, Berlin (2004), pp. 337–370.

¹¹ Lee, S and B. Bozeman (2005), “The impact of research collaboration on scientific productivity”, *Social Studies of Science* 35 (5), pp. 673–702.

¹² Narin, F. (1991), “Globalization of research, scholarly information, and patents: ten year trends”, *Proceedings of the North American Serials Interest Group (NASIF) 6th Annual Conference*, June 1991, *The Serials Librarian*, 21.

Doré et al., 1996⁴; Georghiou, 1998⁵; Glänzel, 2001⁶; Wagner and Leydesdorff, 2005⁷; Jappe, 2007⁸).

The burgeoning literature demonstrates that collaboration in science and technology is growing and is gaining importance in the case of emerging domains of science and technology. At this juncture, it would be appropriate to understand the strategies and drivers of collaborations in nanotechnology in different countries and see how policies relating to partnerships have fomented innovation in these countries.

USA

Background

The role of partnerships in the US has to be seen in the background of shift in composition of private sector research, the funding level of which has witnessed a steady increase over the years in comparison to the public research funding. There has been a shift in industry focus away from basic research to applied product oriented work and outsourcing of basic research activities to small start-ups, independent research houses and contract research organizations and also partnering with universities and national laboratories is increasingly evident⁹.

At the same time, the US has experienced a largely unplanned shift in the allocation of public R&D (Merrill & McGeary, 1999)¹⁰. The life sciences witnessed an increase in federal research funding in one hand, while there was a reduction in physical sciences and engineering in the other hand. The

¹ Luukkonen, T., Persson, O. and Sivertsen, G. (1992), "Understanding patterns of international scientific cooperation", *Science, Technology and Human Values*, 17(1), pp. 101–126.

² Luukkonen, T., Tijssen, R.J.W., Persson, O. and Silversten, G. (1993), "The measurement of international scientific collaboration", *Scientometrics* 28(1), pp. 15–36.

³ Miquel, J. F. and Okubo, Y. (1994), "Structure of international collaboration in science, Part II: Comparisons of profiles in countries using a link indicator", *Scientometrics*, 29, pp. 271–297.

⁴ Doré, JC, Ojasoo, T. and Okubo, Y. (1996), "Correspondence factorial analysis of the publication patterns of 48 countries over the period 1981–1992", *J. American Society for Information Science*, 47, pp. 588–602.

⁵ Georghiou, L. (1998), "Global cooperation in research", *Research Policy*, 27, pp. 611–626.

⁶ Glänzel, W. (2001), National characteristics in international scientific co-authorship relations. *Scientometrics*, 51, pp. 69–115.

⁷ Wagner, C. and Leydesdorff, L. (2005), Mapping the network of global science: Comparing international co-authorships from 1990 to 2000. *Int. J. Technology and Globalization*, 1(2).

⁸ Jappe, A. (2007), "Explaining international collaboration in global environmental change research", *Scientometrics*, 71(3), June 2007, pp. 367–390

⁹ Chesbrough, Hank (2001), Is the Central R&D Lab Obsolete? *Technology Review*, April 24

¹⁰ During World War II and the Cold War era, there was a huge increase in the level of government procurement and support for high-technology industries. The end of the Cold War period witnessed reductions in federal R&D funding in real terms for some disciplines.

promises and potential of biotechnology in the health sector resulted in increasing federal support toward biomedical research. However, this difference in funding trends has worried policy makers in the US and there is a growing concern that this may jeopardize country's global competitive position in the development and commercialization of emerging technologies. This is due to the fact that the interdisciplinary nature of emerging technologies would require an equal emphasis across disciplines and a reduction in federal support for computing research and semiconductor technologies, which supports commercialization of biomedical products, may impact US leadership in innovation and commercial applications in semiconductors, computers and related applications¹.

Box 2.1: Recommendations of the Committee for Government-Industry Partnerships in Biotechnology and Information Technologies

According to the Committee's report on *Capitalizing on New Needs and New Opportunities: Government-Industry Partnerships in Biotechnology and Information Technologies*, government-industry and university-industry partnerships have often been effective in supporting the development of new technologies.

Key recommendations:

- Government and industry should expand support of research partnerships and other cooperative arrangements within and among sectors (government, industry, university, and non-profit) and take other steps to facilitate multidisciplinary research leading to advances in biotechnology and information technology.
- The scientific community, US industry, and the federal government should explicitly examine the implications of recent shifts in the allocation of federal investments among fields (especially the decline in federal funding for research in the physical sciences and engineering) and address possible solutions.
- Federal policy makers should support an infrastructure and create an environment conducive to research partnerships and other cooperative arrangements. Such an environment can be facilitated, for example, through building interdisciplinary competence in multidisciplinary training of graduate students, and a review of the impact of patent decisions on technological progress

Source: National Research Council, 2002

Although public-private partnerships has benefited the US from the early years, it is in the light of above developments that a greater focus on partnerships has been laid down in the Committee for Government-Industry Partnerships in Biotechnology and Information Technologies (see, Box 2.1)

The Policy response

It would be important to state that although individual entrepreneurs and researchers taking the lead in developing innovations and starting new businesses characterize the US

¹ National Research Council (2002), *Capitalizing on New Needs and New Opportunities in Biotechnology and Information Technologies*, C. Wessner, ed., National Academy Press, Washington DC

economy, according to Ruttan (2001)¹, “government has played an important role in technology development and transfer in almost every US industry that has become competitive on a global scale” (See, Box 2.2). Also, the economy is marked by an environment of interaction among government funded research and innovative entrepreneurs and industry.

Box 2.2: Evolution of public role in partnerships in the US

“By the late 1980s, a new paradigm of technology policy had developed. In contrast to the enhanced spin-off programs – enhancements that made it easier for the private sector to commercialize the results of mission R&D – the government developed new public-private partnerships ... [T]hese new programs ... incorporate features that reflected increased influence from the private sector over project selection, management, and intellectual property ownership. Along with increased inputs private sector partner also absorb a great share of the costs, in some cases paying half of the project cost.

The new paradigm has several advantages for both government and the private sector. By treating the private sector as a partner in federal programs, government agencies can better incorporate feedback and focus programs. Moreover, the private sector as partner approach allows the government to measure whether the programs are ultimately meeting their goals: increasing research efficiencies and effectiveness and developing and deploying new technologies.”

– *Office of Technology Policy 1996, pp. 33-34*

For the US, public-private partnerships are important from the perspective of policy implementation and programme supervision^{2,3}. In the early 1980s, the US government brought about extensive changes in antitrust and intellectual property rights regulation and a series of legislative actions starting with the 1980 Bayh Dole Act were authorized. This stimulated research partnerships between universities, government laboratories and industry (Table 2.2). On the one hand the industry wanted to collaborate with the government in response to the intense competition they were facing from producers in fast-follower countries (read Japan) that promoted cooperative R&D for technology acquisition, assimilation and diffusion, while the policy makers interest on the other hand stemmed from the concern of losing out on the front of economic competitiveness and technology leadership. Furthermore, in order to link research and industry, the US government has replaced the Advanced Technology Programme (ATP) with the Technology Innovation Programme (TIP), with a focus on small and medium-sized high-technology firms. The new initiative provides for greater industry input in programme operation and allows university participation for the first time.

¹ Ruttan, Vernon W (2001) *Technology, Growth and Development: An Induced Innovation Perspective*. Cambridge University Press, New York, 588 pp.

² Osborne, D. and T. Gaebler (1993), *Reinventing Government: How the Entrepreneurial Spirit is Transforming the Public Sector*, Plume, New York

³ Shapira, P., Kingsley, G., and Youtie, J. (1997). “Manufacturing Partnerships: Evaluation in the Context of Government Reform,” *Evaluation and Program Planning*, 2, 1, pp. 103-112

Table 2.2 Key federal technology transfer initiatives in the US since 1980

Legislation	Key points
Stevenson-Wydler Technology Innovation Act 1980	Made technology transfer a mission of the federal government and established the Office of Research, Technology and Applications (ORTAs)
Bayh-Dole Patent and Trademark Act 1980	Allowed universities, not-for-profit organizations, and small businesses to retain certain rights related to inventions they developed under funding agreements with the government
Small Business Innovation Development Act 1982	Required federal agencies to provide special set aside funds for small business R&D
Amendment to Bayh-Dole Patent and Trademark Act 1984	Deleted term limitations on exclusive licenses and designated the Secretary of Commerce to determine "exceptional circumstances" when contractor rights might be overruled
National Cooperative Research Act 1984	Encouraged joint R&D ventures among competing private firms to enhance U.S. industrial competitiveness by allowing an exemption from treble damages in private antitrust legislation for registered ventures
Federal Technology Transfer Act 1986	Amended the Stevenson-Wydler Act to authorize the Cooperative Research and Development Agreement (CRADA) for government-owned, government operated laboratories (GOGOs) and formed the Federal Laboratory Consortium (FLC) for Technology Transfer
Executive Order 12591 and 1218, 1988	Required federal agencies to delegate authority to government-operated laboratories to enter into cooperative agreements; provided the authority to enhance the global trade position of the U.S.
Omnibus Trade and Competitiveness Act 1988	Established regional university-based Manufacturing Technology Centers for the transfer of advanced manufacturing techniques to small & medium-size firms
National Competitiveness Technology Transfer Act (NCTTA) 1989	Amended the Stevenson-Wydler Act to establish technology transfer as a federal laboratory mission and permit CRADAs for government-owned, contractor operated laboratories (GOCOs)
American Technology Preeminence Act 1991	Extended the FLC mandate through 1996, allowed the exchange of intellectual property between participants in a CRADA, and allowed laboratory directors to gift excess equipment to not-for-profit organizations
Small Business Technology Transfer Act 1992	Established the Small Business Technology Transfer Research (STTR) Program
Nanotechnology Innovation and Prize Competition Act 2008	Establishes an X-Prize competition for nanotechnology to stimulate public-private partnership and focus investment towards key goals. The bill identifies five key categories – green nanotechnology, alternative energy, human health, nanoelectronics, and commercialization of consumer products, – and establishes a board comprised of government and private sector experts to select criteria for prize competitions.

Source: NTTC, 1996¹; Bozeman, 2000²

Public-private partnerships in nanotechnology

To correct for the market failure that results in under investment in R&D by firms, its cause should be ascertained beforehand and necessary policy measures (public-private partnership) should be adopted. In this regard to address the barriers that caused the market failure, the US government plays an important role in the innovation process.

¹ NTTC (1996), Technology Transfer Resource Guide, National Technology Transfer Center, Wheeling College, Inc.

² Bozeman, B. (2000), "Technology transfer and public policy: a review of research and theory." Research Policy 29(4-5), pp. 627-655

As nanotechnology has application potential in several industry sectors, to promote nanotechnology the government has established new approach for interaction with industry besides the previous models in supporting industry academia government collaboration. Joint Consultative Board of Nanotechnology (CBAN) have been formed in various industry sectors (See, Box 2.3).

Box 2.3: Collaborative Boards for promotion of nanotechnology

The NNI has established new approach for collaboration in nanotechnology. Joint Consultative Board of Nanotechnology (CBAN) have been formed between NNI and industry sectors including the electronic, chemical, biotechnology industry sectors and Industrial Research Institute. The main objectives of such collaborative arrangements are:

- Encourage collaborative activities and joint planning in key R&D areas
- Dissemination of the R&D results to industry and encourage technology transfer
- Identification and promotion of new research gaps in current research programmes, including those with potential in niche markets.
- Exchange of information. Giving more voice to industry to propose R&D topics

Acknowledging the important role of universities in the industrial development process, the series of legislative actions that were undertaken to promote public-private partnerships in the US since the 1980s, has resulted in transfer of knowledge and technologies to society through both formal and informal mechanisms¹. The importance of university research in development of products and processes in high-tech industries were realized in the US way back in 1970s (Mansfield 1991)² and henceforth, universities have been used strategically in various regions such as, California, San Jose, Boston, Massachusetts etc., to attract high-tech industries.

Co-publications in nanotechnology

As observed in high-tech industries, the science based technology fields like nanotechnology have witnessed a high degree of university-industry collaboration in the US. The industry research is much under the influence of university science with about half of the firms, mostly new nanotechnology based firms, having collaborated with university scientists to publish a paper in nanotechnology (Figure 2.1).

¹ Etzkowitz, H., A. Webster, et al. (1998), *Capitalizing Knowledge: New Intersections of Industry and Academia*. Albany, NY, State University of New York Press

² Mansfield, E. (1991), "Academic Research and Industrial-Innovation." *Research Policy* 20(1), pp. 1-12

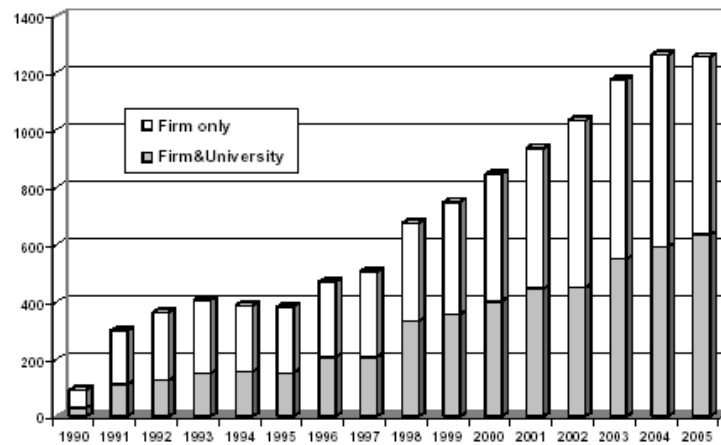


Figure 2.1 Nanotechnology publications from scientists in the industry sector

Source: Wang, 2007

Further, around 40 percent of the universities (700 in nos.) engaged in nanotechnology research were found to have collaborative publications with industry. The list of most active university-industry collaborators in nanotechnology in the US is provided in Table 2.3. There is a trend among universities to collaborate mostly with large established firms and there are only very few universities that collaborate with both large established companies as well as new nanotechnology-based firms.

Table 2.3 Top 10 universities and firms that most actively collaborate in nanotechnology research, 1990-2006

Rank	Universities	No. of collaborative publications	Firms	No. of collaborative publications
1	Massachusetts Institute of Technology	172	IBM Corp.	643
2	University of California – Berkeley	168	Lucent Technology	129
3	Stanford University	165	Dupont Co. Inc.	92
4	University of Illinois – Urbana Champaign	156	Intel Corp.	90
5	University of Minnesota	132	Motorola Inc.	88
6	North Carolina State University	114	Eastman Kodak Co.	79
7	Arizona State University	112	Xerox Corp.	72
8	Cornell University	104	ExxonMobil Co.	71
9	University of Florida	103	Dow Chemical Co. USA	68
10	Pennsylvania State University	99	Procter & Gamble Co.	44

Source: Wang, 2007¹

Co-patenting in nanotechnology

Patents have been used as an indicator of technology innovation. In comparison to the universities it has been found that firms dominate the nanotechnology patent landscape in the

¹ Wang, J (2007), Resource Spillover from Academia to High Tech Industry: Evidence from New Nanotechnology-Based Firms in the U.S. PhD Theses Georgia Institute of Technology December 2007

US. However, the role of university in invention and commercialization of nanotechnology cannot be undermined and needs attention. Around 35 US universities are active in co-patenting with firms (Table 2.4). Also, a large number of university professors are the only inventors in firm patents.

With respect to commercialization it has been observed that the universities are the major source of intellectual property licensed by nanotechnology start-ups¹. The nanotechnology company Nanosys, for example, in order to build a dominant technology and intellectual property estate, has licensed intellectual property from the following universities: Columbia, Harvard, LBL, Massachusetts Institute of Technology, UCLA, UC Berkeley, and Hebrew University (ibid.).

Further, to successfully commercialize university inventions, it has been found that in majority of the cases (70 per cent) the involvement of inventors is crucial². For example, Axon Technology Corporation was formed with intellectual property from Arizona State University and the professor who generated the intellectual property is involved with the company (Waitz & Bokhari, 2003).

Table 2.4 Universities co-assignees with firms on nanotechnology patents

Assignee	No. of co-patents
Duke University	11
University of California	6
University of Tennessee	4
University of Arizona	3
Iowa State University	3
University of Chicago	2
Boston University	2
California Institute of Technology	2
Massachusetts Institute of Technology	2
Northwestern University	2
Rutgers University	2
Stanford University	2
University of Michigan	2
University of Washington	2

Source: Wang, 2007

¹ Waitz, A. and W. Bokhari. (2003), Nanotechnology Commercialization Best Practices. Accessed on May 29, 2009, from http://www.quantuminsight.com/papers/030915_commercialization.pdf

² Darby, M. R. and L. G. Zucker (2003), Grilichesian Breakthroughs: Inventions of Methods of Inventing and Firm Entry in Nanotechnology. Cambridge, MA, National Bureau of Economic Research

Europe

Background

The 'European paradox', which highlights the gap between high scientific performance and industrial competitiveness, warrants the need for efficient interface between public research and industry. In this regard, several European countries have increased its focus on public-private partnerships and efforts are being made to strengthen linkages in the public and private sector through developing new programmes and initiatives (see, Table 2.5).

The predominance of a type of public-private partnerships reflects different institutional structure and research specialization in countries. In many European countries, university research is mostly supported by internal research funds. However, in the wake of shortage of funds, universities have diversified their sources of funds, for example, in countries like Belgium, the Netherlands and the United Kingdom. Since 1980s, the trend of industry financing university research has further increased significantly in countries like Germany and the Netherlands. The growing cooperation between university and industry could be explained in terms of: the need to diversify the funding portfolio of universities, including funds from non-government sources; increasing competition and shortening of time period of R&D pushing the industry to access a broader science-base than available in-house; and a thrust on greater returns from government support of R&D¹ (Senker, 1999).

Table 2.5 Nanotechnology – Key programmes and initiatives in Europe

Country	Key Programmes/Initiatives
Austria	<ul style="list-style-type: none"> ▪ COMET (Competence Centres for Excellent Technologies) 1997 - Addresses existing competence centers, networks and consortia with participants from science and industry ▪ Christian Doppler programme – Establishes research centers (CD labs) in universities and non-university research centers with equal funding from public authorities and private institutions ▪ Innovation voucher scheme – a joint initiative between BMVIT (Federal Ministry for Transport, Innovation and Technology) and BMLWB (Federal Ministry of Economics and Labour) – to support cooperation between SMEs and public research organizations with Euro 5000 per voucher
Italy	<ul style="list-style-type: none"> ▪ Creation of joint labs between universities or public research bodies and private industry in specific research areas (new materials, biotechnology, nanotechnology etc.) ▪ Creation of technological districts to promote innovation capacity of SMEs linking them with high technology firms, universities, public research organizations, financing bodies and local communities
Spain	Increased direct funding to industrial research and technology development through initiatives like CENIT (National Strategic Consortia for Technical Research), 1996 with a focus on funding of bigger projects involving public private partnership
Netherlands	<ul style="list-style-type: none"> ▪ Innovation voucher scheme for SMEs to buy knowledge from public or private knowledge

¹ Senker, J. (1999), Changing Structure, Organisation and Nature of European PSR Systems. Synthesis Report. (SPRU, University of Sussex, Brighton, 1999)

Country	Key Programmes/Initiatives
	institutes (including large firms). <ul style="list-style-type: none"> ▪ Launching of Leading Technology Institutes (LTIs) as a successful model of public-private cooperation in various areas
Germany	Research bonus programme (<i>Forschungsprämie</i>) 2007 for cooperation between science and industry, particularly SMEs. Universities and research institutions carrying out R&D for SMEs to get a bonus equivalent to 25% of the volume of contract awarded by SMEs
Denmark	Programme for User-driven Innovation to improve the innovative abilities of industry and public institutions in order to tap user's innovation potential
France	Cluster policy initiative (<i>poles de competitivite</i>) to pool the competencies of public and private research organizations, training centers, and industry for innovative projects
Belgium	Tax incentive scheme to promote collaboration between public research and industry. A company collaborating with a public research institution can get a 50% reduction of the advance tax due by the researcher

Source: OECD, 2008¹

The policy response

In the early 1980s, as in the US, the European Community (EC) was facing the challenge of gradual loss of international competitiveness in the high-technology sectors. In addition, there were several other factors influencing the EC policy like, non-uniformity in research and technology capabilities of the member countries, differences in S&T policy infrastructure of various country members and lack of appropriate legal framework at the EC level to support a consistent technology policy (Hagedoorn, 2000).

To address the above-mentioned challenges at the EC level, the Single European Act of 1987 was enacted, which created the legal basis for central science and technology policy. Further, to promote cooperative R&D a series of successive European Framework Programmes on R&D (FWPs) were initiated in 1984 in which a wide range of participants including private companies (SMEs, private research institutes or other industrial participants), public organizations (public universities, regional authorities, public research organisations (PROs)), individual researchers (from both the public and the private sector), and researchers and organizations outside the EU can participate with a caveat that the participating institutions should be based in at least two EU member countries. Presently the seventh FWP (2007-2013) is under operation.

Some of the recent policy initiatives in public-private partnerships in Europe is mentioned in Box 2.4. Although there are diversity in the S&T policy infrastructure and approaches to collaborative R&D of the EU member countries including the role of the government in promoting and regulating research partnerships, nonetheless, it could be generalized that

¹ OECD (2008), OECD Science, Technology and Industry Outlook, Organisation for Economic Cooperation and Development, Paris

governments at all levels across Europe have tried to use research partnerships as means to strengthen the links between university, industry, and government laboratories.

Box 2.4: Recent Policy initiatives in Europe: public-private partnerships, networks and co-operation

European Technology platforms: The main stakeholders in a technology field are grouped which develops a medium to long-term research agenda to address strategic technological challenges. The platforms are invited to identify issues related to the regulatory framework for the technologies concerned. This can enable early identification of issues that might hamper the development of new technologies and facilitates early adaptation of regulations and standards.

Joint Technology Initiatives (JTI): These are initiatives emerging from European technology platforms and are partly funded by FP7 funds and industry. Launches calls which are open to stakeholders from public bodies, academia and industry (EU and associated countries). Six areas having relevance include: hydrogen and fuel cells, aeronautics and air transport, innovative medicines, nano-electronics (ENIAC), embedded computing systems (ARTEMIS) and global monitoring for environment and security.

European Institute of Technology (EIT): Function as a hub in a broader network linking business and public research. The EIT has two levels: a governance structure that is based on its Governing Board (GB) and knowledge and innovation communities (KICs) which are autonomous partnerships of universities, research organizations, companies and other stakeholders.

Source: OECD, 2008

Public-private partnerships in nanotechnology: the case of Germany

Germany, the leading player in nanotechnology in Europe, has a high-class R&D infrastructure and research capability in the various nano sub-fields besides having a suitable industrial base for commercialization. More than 1000 companies are actively working in this field, with an estimated EUR 420 million public-sector investment in 2008¹.

Co-publications in nanotechnology

A key distinguishing feature of the German research system is the relatively large share of extra-university research. A network of research institutes – Fraunhofer, Max Planck, and Leibniz – act as an effective interface between basic research and industry. This institutional differentiation poses a challenge to the German research system in establishing research partnerships. However, the case of Germany shows that in the field of nanotechnology there is a high degree of research collaboration between extra university research sector and universities. This is evident from the figures, provided by Heinze and Kuhlmann (2008)², on co-publications between German research institutions in nanotechnology (see, Table

¹ Nanotechnology in Germany – Programmes, networks, funding, research groups and companies, Nanoposts Jan. 2009 pp. 86

² Heinze, T. and Kuhlmann, S. (2008), "Across institutional boundaries? Research collaboration in German public sector nanoscience", Research Policy

2.6). The study of Heinze and Kuhlmann (2008)¹ identified various types of research collaborations in nanotechnology in Germany viz., formal and informal collaborations. The various types of formal collaborations included *cooperation contracts* between research institutes for use of research instrumentation and exchange of personnel; *junior research groups* at the intersection of institutes sharing instrumentation and personnel costs; and *education of junior researchers* between university and extra-university sector as well as within extra-university sector. The various forms of informal collaborations included meetings of the heads of institutes and travel by doctoral students between sites.

Table 2.6 Co-publications between German research institutions in nanotechnology, 1999-2003

	Universities	Helmholtz Research Centres	Max-Planck Society	Fraunhofer Society
Universities	-	375 (18%)	568 (86%)	107 (78%)
Helmholtz Research Centres	375 (36%)	-	74 (11%)	12 (9%)
Max-Planck Society	568 (54%)	74 (16%)	-	18 (13%)
Fraunhofer Society	107 (10%)	12 (3%)	18 (3%)	

Source: Heinze & Kuhlmann, 2008²

Effective inter-institutional knowledge flows between university and extra-university research sector is one of the key factors explaining Germany's dominance in the global nanotechnology race. The rationale for research collaboration across institutional boundaries in Germany, which is characterized by high degree of institutional differentiation, could be explained in terms of (Heinze and Kuhlmann, 2008)³:

- Expansion of research capacity, which includes, the need for complementary knowledge and expertise; access to equipment and instrumentation; and the ability to build consortia that compete for funding;
- Improvement of current research capabilities, which includes, keeping own research activities focused and learning new skills or techniques;
- Realisation of institutional complementarities; and
- Enhancement of visibility of research institutions for scientists and companies in the field

However, this trend has not been observed between organizations of the extra-university public research sectors.

¹ *ibid.*

² *ibid.*

³ *ibid.*

Co-publications network in Germany has developed a core-periphery relationship. Heinze (2006)¹ in his study on emergence of nano S&T in Germany found that at an early stage of development (1991-1995) it was the large companies that contributed substantially to publications in nanotechnology, however, in the later period (1996-2000) the public research sector (universities as well as extra-university institutes) moved into the network core and were found to be the major actors in the nanotechnology publications landscape. The study further observed that the underlying research base, mostly in universities and extra-university research organizations, catalyses development of nanotechnology in Germany and that there is a substantial knowledge transfer between the public research sector and the private sector in this field.

Co-patenting in nanotechnology

The core-periphery structure predominant in the co-publication network has not been observed in the co-patent network structure. The companies dominate the nanotechnology patent landscape in Germany, although extra-university research institutions are also found to be increasingly patenting in nanotechnology. However, there are few instances of collaboration between research institutes and companies². Matching inventor names with SCI authors, Heinze (2006)³ tries to capture in his study the co-patenting network between companies and research institutes. The following observations were made by him, which has important policy implications:

- Companies, mostly high-tech companies⁴, like to collaborate with those research institutes which display scientific strength but are still involved to a certain extent in technological problem solving. In other words, companies interact most intensely with those public research institutes that perform both basic research as well as applied research⁵. Comparing interaction patterns of fundamental and basic research institutes with companies, strong relationships were observed between high-tech companies and applied research institutes in comparison to high-tech companies

¹ Heinze, T (2006), "Emergence of Nano S&T in Germany. Network Formation and Company Performance", Fraunhofer ISI Discussion Papers Innovation System and Policy Analysis, No 7/2006, Karlsruhe, April 2006

² Data on co-patenting between companies and research institutes may not be captured fully as in many cases the public researchers involved in co-patenting usually appear as inventors with their private address. As such, co-patenting between companies and research institutes have been mostly of the nature of applicant-inventor.

³ Heinze, T (2006), "Emergence of Nano S&T in Germany. Network Formation and Company Performance", Fraunhofer ISI Discussion Papers Innovation System and Policy Analysis, No 7/2006, Karlsruhe, April 2006

⁴ These have higher share of R&D investment relative to company turnover (OECD 2001). Unlike USA, majority of firms are incumbents, new nanotechnology based firms entered the field in the later part of 1990s

⁵ Stokes (1997) termed this as use inspired research signifying research that is neither purely fundamental nor fully applied.

and fundamental research institutes.

- Exclusive ties exist between companies and public research institutes, however, multiple company- multiple research institutes cooperations are commonly observed. It is found that firms compete for research organizations and collaborate with several public sector research institutes to enhance their knowledge base and gain scientific visibility. However, unlike the patterns found in the US where start-ups in nanotechnology were founded around star scientists¹, in Germany there is no clear regional distribution and the start-ups do not play a significant role.
- Companies having high collaboration with research institutes were found to be performing better and multiple interaction channels were found to be consequential in enhancing the firms' technological capabilities. The nanotechnology companies are dependent to a large extent on the public research base, and technological progress would be much slower if collaborative ties do not exist between companies and public research institutes.

Thus, in the case of Germany, both co-patent and co-publication networks were found to be important in strengthening technological capabilities of firms. Further, since the field of nanotechnology cuts across established disciplinary and sectoral boundaries, multiple interaction channels enable companies to gain access to the latest advancements and enhance their performance. Also, companies profit most from collaborating with research institutes and universities having scientific base, both basic and applied.

Centers of excellence: enhancing knowledge flows in nanotechnology

In order to pool specialised knowledge in nanotechnology and accelerate innovative processes by strategic information exchange, a network of centres of competence linking universities, research institutes, companies, financial service providers, consultants and associations is probably an unique arrangement which enables knowledge flows and exchange among various agents in Germany. Besides working in different subject areas both at the national level and in regional clusters, these networks also focus on training and education. Table 2.7 provides details of the competence centers in Germany. Further, several centers of nanotechnology is being established in the universities in Germany, which acts as a platform for industry collaboration and formation of spin-off companies. Table 2.8 provides the details of nanotechnology centers in select universities along with their research focus.

¹ Darby, M. R. and L. G. Zucker (2003), Grilichesian Breakthroughs: Inventions of Methods of Inventing and Firm Entry in Nanotechnology. Cambridge, MA, National Bureau of Economic Research.

Table 2.7 Centres of Competence in nanotechnology in Germany

Centre of Competence	Description
Nanotechnology Centre of Competence "Ultrathin Functional Films" (Saxony region)	A network of 51 companies, 10 university institutes, 22 research establishments and five associations coordinated by the Fraunhofer Institute for Material and Beam Technology (IWS) Dresden with a goal to exploit industrial application potential.
CC-NanoChem/NanoBioNet – Networks for Chemical Nanotechnology/Nanobiotechnology (Saarbrücken/Saarpfalz region)	CC-NanoChem centre of excellence specialising in chemical nano technology and NanoBioNet network with a focus on the interface between nanostructure science and biology, offer a forum for exchange between universities, research centres, small, medium-sized and large enterprises, as well as consultants and venture capitalists. Expert assistance to start-ups is also provided in these centers.
ENNaB – Excellence Network NanoBioTechnology (Munich region)	In its role as the link between university and industry – between basic research and industrial application, ENNaB – Excellence Network NanoBioTechnology, provides training to competent research and management personnel for universities and industry, in order to facilitate commercial implementation of new, innovative applications in the field of nano-biotechnology.
CCN – Competence Center for Nanoanalytics (Münster Region)	The main tasks of the network include the continued development of nanoanalytic measuring methods, their adaptation to technological demands and their standardisation.
IVAM Microtechnology Network (Ruhr region)	A network of 250 companies, institutes and partners aims to make technological developments in the area of microtechnology, nanotechnology and new materials known to a broader public and market them. Helps small and medium-sized enterprises to bring innovative technologies and products to market and thus stake their claim in international competition.
HanseNanoTec Competence Centre (Hamburg region)	Combines the Hanseatic city's expertise in this sector and initiates and promotes cooperation with supraregional and international partners. The objective is to optimise efficient acquisition of basic insights and swift transformation of nanotechnology knowledge into products, manufacturing processes and services.
UPOB – Competence Centre Ultraprecise Surface Figuring (Brunswick region)	To bundle capabilities across different area, the Brunswick nanotechnology competence centre is a cluster amalgamating production technologies, machines and machine components, metrology, sensor technology and materials. As the respective methods used differ significantly, the network is divided up into four core areas: mechanical/chemical processing, ion beam and plasma processing, optical processing and related topics, and characterisation of surfaces.
NanoMat (Karlsruhe region)	The network with a focus on nanomaterials comprises of three research centres of the Helmholtz Association, ten universities with natural science and engineering departments, a Max Planck institute, a Leibniz institute, a Polish Academy of Sciences institute, three Fraunhofer institutes, the Society for Chemical Engineering and Biotechnology (DECHEMA), and four large corporate groups.
NanOp – Competence Centre for the Application of Nanostructures in Optoelectronics (Berlin/Brandenburg region)	The NanOp centre of competence, a network comprising universities, research establishments for applied and basic research, industrial enterprises, and banks as well as venture capital firms, is engaged in research and development in nanotechnologies for application in new and revolutionary products based on nanooptoelectronics. Close cooperation between all the partners involved in the network and fast transfer of know-how produce synergy effects.

Source: www.research-in-germany.de

Table 2.8 Nanotechnology centers in Universities in Germany

Nanotechnology Centres	University	Description
NanoClub	Technical University, RWTH Aachen	Bundles the widely spread expertise of the various departments in the field of nanotechnology and cooperates with participants from industry, the Jülich Research Centre and numerous Fraunhofer institutes.
Centre for Functional Nanostructures	University of Karlsruhe (TH) and Research Centre Karlsruhe	More than 200 scientists and technical staff from the departments of physics, chemistry, electrical engineering and information technology, chemical process engineering and from the Institute for Nanotechnology (INT) work at the Centre for Functional Nanostructures on the fundamental principles of new electronic and photonic devices.
Centre of Nanophotonics	University of Technology Berlin (TU Berlin)	Founded in 2004 to cater to the extremely high industrial demand for qualified personnel in the fields of semiconductor-based technologies and devices and to enable the development and processing of novel complex optoelectronic devices based on nanostructures. The institute's training, research and development work has led to the foundation of a whole series of successful spin-off companies.
Centre for Nanotechnology (CeNTech)	Münster University	Aims to initiate spin-offs in the field of nanotechnology and support companies in the nano sector. CeNTech is also involved in extending training and further training measures. By organising specialist events like the congress fair NanoBio-Europe, as well as special workshops, both researchers and start-up entrepreneurs are offered an international forum for debate and initiating new collaborations and alliances.
Centre for NanoScience (CeNS)	Munich University (LMU)	Promotes interdisciplinary research and teaching in fields dealing with objects and functions on the nanometre scale. CeNS promotes cooperation between different scientific disciplines by pooling knowledge, technologies, facilities and resources, and also invigorates interdisciplinary training by means of joint teaching modules and workshops. The centre endeavours to establish collaboration with industry.

Source: www.research-in-germany.de

Japan

Background

In the period before 1998, in Japan, public–private partnerships involving national universities and industry were mostly informal in nature and it was the large established companies that happened to be the main industrial collaborators. In this regard, Kneller (2003)¹ pointed out that although informal technology transfer between universities and private sector in Japan looks more efficient than formal one, there exist some problems such as *de facto* preferential treatment to the large firms, disincentive to firms for further development caused from unclear intellectual property rights and so on. University researchers and administrative employees played a passive role. Lack of proper rewards for

¹ Kneller, Robert (2003), University-Industry Cooperation and Technology Transfer in Japan Compared with the U.S.: Another Reason for Japan's Economic Malaise?, 24 University of Pennsylvania Journal of International Economic Law, 329

collaboration in the universities acted as a disincentive for the researchers to actively engage with industry. However, Japanese companies, in order to increase their absorptive capacity, used to send their employees to university labs and conduct joint research with university professors without any licensing arrangements with universities.

From 1998 new legal frameworks have been enacted in Japan and a US-style legal framework has been adopted to bridge the gap between industry and universities (see, Box 2.5). This resulted in increased university-industry technology transfer and led to the emergence of a large number of spin-offs based on university basic research and technology breakthroughs (Tanaka, 2006).

Box 2.5: Recent policy initiatives to promote university-industry linkages

- Subsidies for joint university-industry research (1983)
- Establishment of cooperative research centers at national universities (1987)
- The TLO Law (1998): Law to promote transfer of university technologies. Established as independent for-profit corporations and affiliated with national universities.
- Japanese version of Bayh-Dole Act (1999)
- Law to Strengthen Industrial Technology (2000): To encourage entrepreneurship among university researchers, the law legalized compensated consulting and the holding of line management positions in private companies and encouraged the commercialization of university discoveries in the case of management positions.
- MEXT policy directive (2002): University got the right to claim ownership of work related inventions, and the inventors the right to 'reasonable remuneration.'
- National University Corporation Law (2004): To increase autonomy and accountability, introduce greater diversity and allow the best to compete internationally, national universities were removed from direct government control and became 'National University Corporations' with as status of independent administrative units within the Japanese government structure.

Besides growing cooperation between universities and industry since the late 1990s, university-industry collaboration in Japan is also characterized by cooperation between the two ministries (METI and MEXT),

Public-private partnerships in nanotechnology

Government agencies and large corporations are the main sources of funding for nanotechnology in Japan; small and medium-size companies play only a minor role. Also, Japanese industry finances a substantially greater proportion of the R&D that it undertakes compared to the US and Europe.

Japan is a heavy investor in nanotechnology R&D. However, Japanese R&D investment is not commensurate with the outputs expected from such investments, which could be explained by a number of structural features viz., weak linkages

between industry and public research organizations, low level of openness to international trade and investment, little international R&D linkages and, low venture capital investments (OECD 2008). To overcome the weak linkages between industry and academia, the Ministry of International Trade and Industry (MITI) – the main government organization sponsoring nanotechnology in Japan – awards projects to universities that encourage use of research professionals from industry.

The Japanese government went for a systems reform under the 2nd S&T Basic Plan (2001-06) and removed direct government control from universities making them ‘independent administrative agencies’. This was done with a view to increase autonomy and accountability, introduce greater diversity and allow the best to compete internationally. As a result, there was a spurt in the number of university spin-offs. Also, to promote technology transfer, Technology Licensing Organizations (TLOs) were set up in universities.

In an attempt to create more links between universities and industry (which has been neglected in Japan in the semiconductor area), another consortium which has just been started up is the Semiconductor Technology Academic Research Center (STARC), which has issued its first round of contracts to university researchers, as it begins its mission of linking corporate and academic researchers, much like the Semiconductor Research Corp. in the U.S. Here, STARC is taking advantage of the revised regulations from the Ministry of Education, which now allows companies to provide research funds to universities directly (previously forbidden).

Trends in international collaboration in nanotechnology

In the recent times there has been a lot of attention on global nanotechnology collaborations. By tracking the international nanotechnology networking and R&D collaborations and the funding opportunities, developing countries can benefit substantially in their quest of engaging with nanotechnology. International R&D collaborations in nanotechnology and funding opportunities at the global level have been depicted in Annexure 1.

One of the basic indicators of collaboration in scientific fields and international co-authorship is the number of publications in international journals, and their share in the total national publication output. Table 2.9 depicts publications in nanoscience from USA, Japan, Germany, France, and China during 1985-2004. The Table shows in detail the countries

involvement in the international collaborative network. European nations like Germany and France have shown a high degree of involvement, for the percentage of international co-publications witnessing an increase from around 23%, during 1985-1994, to around 45%, in the sub-period 1995-2004, in both the countries. Japan and USA have also registered an increase during these sub-periods but their share of international co-authored publications is at a low level compared to the European nations. China, which has emerged as a prolific publisher in nanoscience in the recent years, however has a low level of involvement in the international collaborative network. Its percentage of international co-publications has shown a marginal increase in comparison to other countries under consideration.

Table 2.9 International co-publications of five selected countries in nanoscience during 1985–1994 and 1995–2004

Country	1985-2004		1985-1994		1995-2004	
	Papers	Share (%)	Papers	Share (%)	Papers	Share (%)
USA	9391	24.48	474	12.20	8917	25.86
Germany	6236	41.79	261	23.86	5975	43.21
Japan	3730	21.02	120	9.42	3610	21.92
France	4589	43.13	219	23.32	4370	45.05
China	2764	16.43	49	14.45	2715	16.48

Source: Guan & Ma 2007¹

Foreign collaborative links, as calculated by Guan & Ma (2007), between pairs of countries as depicted in Table 2.10 shows that the five countries of USA, Germany, Japan, China and France are the major partners with each other in the international collaborative network. As evident from the Table, the US is preferred as the first choice for collaboration in nanoscience research. Germany is the largest partner of the US in nanoscience research followed by Japan, China and France. After the US, Germany's largest partners are Russia and France. Similarly, Japan's major partner after USA is China followed by Germany and South Korea displaying a greater tendency towards intra regional collaboration. France collaborates mostly with USA, Germany, Italy and Spain in nanoscience research. Although the US is the first major choice for collaboration, there are certain exceptions to this trend. Russia, Switzerland and Poland have been found to collaborate mostly with Germany. Similarly, Italy, Spain and Belgium's major partner is France.

¹ Guan JC, Ma N. (2007), China's emerging presence in nanoscience and nanotechnology: A comparative bibliometric study of several nanoscience 'giants'. *Research Policy*, Volume 36, Issue 6, July 2007, pp. 880-886

Table 2.10 Collaboration links between pair of countries in nanoscience research

Collaborators	Countries				
	France	China	Japan	Germany	USA
USA	817	824	1187	1491	-
Germany	733	396	394	-	1491
Japan	218	569	-	394	1187
China	121	-	588	396	824
France	-	121	218	733	817
England	373	134	264	449	743
Canada	107	109	91	125	638
Russia	327	37	215	760	559
South Korea	46	131	313	80	522
Italy	508	42	97	309	448
Spain	421	32	64	250	361
Switzerland	249	15	73	427	357
Israel	87	50	31	137	298
The Netherlands	108	31	67	250	252
India	68	22	137	165	244
Brazil	123	24	66	82	215
Sweden	59	55	56	195	213
Belgium	255	36	29	129	209
Mexico	58	12	54	60	203
Taiwan	9	62	48	25	192
Australia	48	101	114	111	191
Poland	219	9	83	251	187
Singapore	2	177	29	21	145
Denmark	32	16	36	104	139
Austria	90	14	26	262	126

Source: Guan & Ma 2007

Key lessons for developing countries

This chapter on dynamics of public private partnerships in nanotechnology arrives at following policy lessons from the perspective of developing countries. The lessons have been dealt with from the standpoint of why partnerships in nanotechnology are important and what does partnerships in nanotechnology entail.

Partnerships is essential in the process of innovation and an important defining feature in emerging technologies

Although partnerships have played an important role in technology development and diffusion in the past, but a committed interaction between the public research institutions and private firms is the precondition for accelerating the development of emerging technology like nanotechnology. Several reasons account for the importance of partnerships in nanotechnology. It may be beyond the ability of any single firm or industry to develop nanotechnology due to the

interdisciplinary character of the technology, complexity of technology, uncertainty and associated risks, high cost of instrumentation, lack of requisite expertise and an inability to capture adequate returns. Further, these new technological paradigms are more knowledge-intensive than in the past and in such conditions the relation to science and research is necessary throughout the entire process. This points towards the importance of collaboration between industry and public research institutions.

The growing interdisciplinary character of scientific and technological knowledge may pose significant challenge to developing countries where the public research institutions and private firms operate at arms length and innovation is still perceived as a linear process (see, Figure 2.2).

Private firms, at the most, worked with university labs in a consulting mode where a short-term interaction was sought for solving a well-defined problem, mostly of trouble-shooting nature. The weak links between R&D performing institutions and industry could not lead to a long-term vision for research driven product or technology development resulting in a weak innovation system.

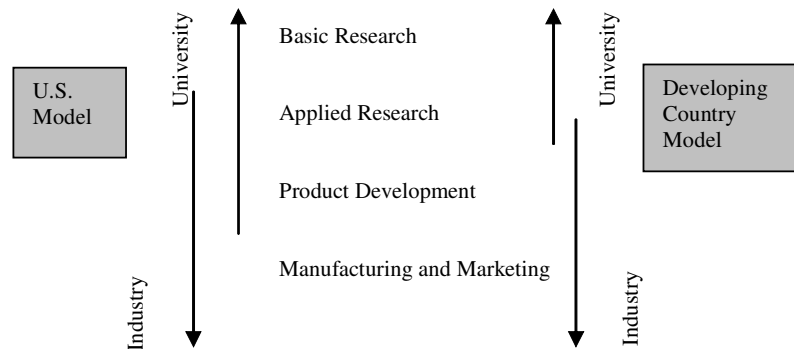


Figure 2.2 University-Industry role in the innovation process in developing and developed countries

It is frequently debated that the role of universities in the knowledge-economy should not only be restricted to the production of knowledge but equally importantly in the commercialization and sharing of it. Therefore, it is important that to overcome this lack of synergy and cooperation between the two sectors there is a need to reconfigure the system under which universities operate to enable them to be entrepreneurial, risk-taking and innovative.

A strong R&D base in the government supported research infrastructure is essential for partnerships in nanotechnology

It is often found that universities or research institutes having a strong R&D base in nanotechnology are the most sought after partners of industry in the innovation process. In many developing economies, investment in universities has either not created research and development capability or the R&D initiatives have not linked with the industrial practice. This could be mostly attributed to the existence of institutional fragmentation and the absence of institutional mechanisms that facilitate public-private partnerships. This has led to the dominance of the 'supply push' culture in universities.

Global networks becoming the locus of innovation and developing countries can benefit by becoming a part of this network

When the knowledge base of an industry is both complex and expanding and the sources of expertise are widely dispersed, the locus of innovation will be found in networks of learning, rather than in individual organizations or firms. The network in this regard provides timely access to knowledge and resources that are otherwise unavailable, while also testing internal expertise and learning capabilities.

International collaboration in nanotechnology, indicated by co-publications and co-patenting trends at the global scale, has witnessed an increase over the years. Given the increasing global interdependences in nanotechnology, developing countries in their pursuit to engage with nanotechnology can benefit by becoming a part of this global network. This would help developing countries to increase their global visibility in frontier cutting edge science and technology besides building their internal research capabilities. However, according to Cohen & Levinthal (1990)¹ to absorb and utilize external knowledge, the necessary prerequisite would be the creation of firm's absorption capabilities through their own R&D efforts. Therefore, developing countries having a critical mass of capabilities could actively participate in the global network and derive benefits from the association.

Government playing a predominant role in facilitating partnerships

From the global developments it could be inferred that the government has played an important role in facilitating public-private interactions to promote nanotechnology in varied ways like

¹ Cohen, W.M. and D.A. Levinthal (1990), Absorptive Capacity: A New Perspective of Learning and Innovation. Administrative Science Quarterly, Vol. 35, pp. 128-152

- Helping in the establishment of technology transfer and industrial liaison offices at universities, technology incubators, science parks and centres of excellence to increase efficiency from public R&D expenditure and diffusion of knowledge.
- Funding of industry consortia to reduce the technical risks of firms
- Promoting the mechanisms, which can build the linkages between public research institutions.
- Acting as a mediator between public research institutions and industry in the innovation processes.

In the set up of developing countries in cases where there is lack of interface settings between university and industry, the state participation has become common in order to ensure the flow of ideas and people between these two important components of the innovation systems¹. Although the role of government changes in response to the market-led dynamism of the economy, it remains the case that to engage successfully with an emerging technology and to address the interaction deficit would require a deft policy hand.

Broaden public-private partnerships involving other actors in the innovation system

Lack of collaboration may be attributed to various reasons. Incompatibilities in the mandate of public research institutions, which focuses on long-term research and firms mandate having a focus on problem-oriented research may be one of the reason for lack of collaboration between these two different set of organizations. Existence of institutional or market disincentives could be another reason. Thus, to overcome the barriers to partnerships, countries have adopted the strategy to broaden public-private partnerships involving both large and small firms and other actors in the innovation system. For e.g., in the case of Manufacturing Extension Partnerships (MEP) programme, SMEs are linked to federal labs, technology brokers and consultants. Similarly, at EU level attempts have been made to encourage SMEs participation in Community Research Partnerships schemes.

Need to evolve a framework of norms to guide interaction

For productive partnerships in nanotechnology it is important to address the gap between the needs of industries and the capabilities of academia. The mismatch between the university research scientists' approach and the applied research focus of the industry acts as a barrier in interaction. Thus there is a need for mechanisms for overcoming the barriers posed by these two very different types of organizations.

¹ Nordfors, D., J., Sandred, and C. Wessner, (2003), Commercialization of Academic Research Results, Vinnova (2003:1)

The mechanisms need to clearly define the guidelines for organizing collaboration projects between private firms and public research institutions. This is important in dealing with the possible differences in anticipated outcome right from the beginning of the project.

One of the reasons why the industry doesn't collaborate with public research institutions in developing countries is the lack of clear guidelines for collaboration. A call is therefore made for providing clear guidelines regarding project management, property rights, division of resources and responsibilities.

ANNEXURE I International collaborations in nanotechnology

Sl. No	Collaborating countries	Area	
1	USA-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-us.htm
2	USA-Germany	Bilateral collaborations in chemistry	http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13627&org=OISE&from=fund and http://www.dfg.de/en/international/index.html
3	Canada-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-ca.htm
4	Argentina-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-ar.htm
			<ul style="list-style-type: none"> - Research council CONICET organises the participation in the CIAM inter-American cooperation programme in Materials, including nanomaterials. www.conicet.gov.ar/coop/convocatoria/CIAM.php - National Agency for Science and Technology Promotion stimulates international R&D collaborations http://www.agencia.secyt.gov.ar/default.htm - The Secretariat for Science, Technology and Industrial Innovation of the ministry of Education, Science and Technology also coordinates international collaborations in Science and Technology. http://www.secyt.gov.ar/
5	Chile-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-cl.htm
6	Australia-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-au.htm
7	China-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-cn.htm
			<ul style="list-style-type: none"> - The Chinese Ministry of Science and Technology (MOST) funds international R&D collaborations. http://www.most.gov.cn/eng/organization/department/office.htm - National Agency for Science and Technology Promotion stimulates international R&D collaborations http://www.agencia.secyt.gov.ar/default.htm - The Secretariat for Science, Technology and Industrial Innovation of the ministry of Education, Science and Technology also coordinates international collaborations in Science and Technology. http://www.secyt.gov.ar/
8	India-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-in.htm
			-Department of Biotechnology of the Ministry of Science and Technology funds international collaborations in life science research, including

			nanotechnology. http://dbtindia.nic.in/proposals/proposalmain.html
			Department of Science and Technology of the Ministry of Science and Technology coordinate a wide range of bilateral and multilateral agreements and stimulate exploratory missions of scientific delegations, events, fellowships, joint R&D programmes and centres of excellence, and access to research infrastructure. The countries and regions they collaborate with include: the European Union, Bulgaria, France, Germany, Hungary, Israel, Italy, Poland, Portugal, Romania, Switzerland, and UK. http://dst.gov.in/scientific-programme/International-s-coop.htm The Council of Scientific and Industrial Research stimulates international collaborating by publishing details of foreign research council grants that are open to Indian researchers (under career development). They also offer funding for attending conferences abroad. http://www.csir.res.in/
9	Japan-UK	Physics of Quantum Nanoelectronics and Application to Novel Devices	http://www.mext.go.jp/english/news/2004/08/05011301.htm
			A "Grant for International Joint Research (NEDO Grant)" includes the field of nanotechnology. http://www.nedo.go.jp/english/introducing/contact.htm
10	Korea- France	The STAR programme (Science and technologies Amicable Relationship) funds several projects like new materials and nanotechnology	http://www.delkor.cec.eu.int/en/whatsnew/7.Experience%20of%20Member%20States%20-%20France.pdf
11	South Africa-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-za.htm
12	Russia-EU	International S&T cooperation agreement including nanotechnology	http://www.cordis.lu/nanotechnology/src/intlcoop-ru.htm