Mapping the Indian nanotechnology innovation system

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Abstract

Purpose – The purpose of this paper is to map out the Indian nanotechnology innovation system. An attempt is made to identify the dominant actors, collaborative pattern and analyse the role of and interactions between the actors and institutions.

Design/methodology/approach – A combination of frameworks such as national and international system of innovation is used to include all possible actors and institutions involved. A scientometric analysis is also carried out.

Findings – Despite a series of government interventions discernible in various programmes since the 1980s, nanotechnology-based industries are yet to emerge as a dominant sector. The health sector has emerged as one of the major contributors in terms of nanotechnology applications. There are many other challenges of safety and standards, socioeconomic, ethical and environmental concerns. Academic R&D labs are active in technology transfer.

Research limitations/implications – A scant literature is available for this sector in India and especially from the international innovation system framework to analyse the socioeconomic and risk governance issues.

Practical implications – A scant literature is available for this sector in India and especially from the international innovation system framework to analyse the socioeconomic and risk governance issues.

Originality/value – A scant literature is available for this sector in India and especially from the international innovation system framework to analyse the socioeconomic and risk governance issues.

Keywords India, Nanotechnology, Innovation systems, International collaborations

Paper type Research paper

1. Introduction

Nanotechnology is emerging as an all-pervasive field finding application in diverse sectors such as agriculture, energy, health, electronics, cosmetics, textiles, water treatment. Many countries across the world, including India, have launched several initiatives in order to tap the enormous potential nanotechnology offers. However, the areas of application might or ought to differ in the developed and the developing countries given the difference in their socioeconomic situation. Nanotechnology has raised hopes and has promised many solutions to issues relating to food, health, environment and industrial productivity and at the same time posed many challenges of safety and standards, socioeconomic, ethical, political, environmental, ethical and legal nature. With the heightened significance, it is needless to emphasise the crucial role of research, development and innovation in the development of nanotechnology. This paper attempts to map the Indian nanotechnology innovation system from the systems of innovation framework. Many scholars (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Edquist, 1997; Breschi and Malerba, 1997; Asheim and Isaksen, 2002; Desai, 2009) have described various systems of innovation. Although there are some scholars who perceive different frameworks, such as national, sectoral, regional and

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international systems of innovation as competitive, a wider consensus is emerging not to treat these frameworks as contradictory.

It is observed that after the government introduced the Nano Science and Technology Initiative (NSTI) in 2001, the publication and patenting activities have witnessed intensification and a sharp increase. It is important to note here that the drug and pharmaceutical sector emerged as one of the major contributor to patenting activity (Panda and Gupta, 2008) and that R&D funding and educational infrastructure also received a great boost during this period. Under the Nanoscience and Technology Mission, various joint projects between academic institutions/R&D labs and industries are being supported that also include some health-related projects. Moreover, it is reported that academic R&D Labs transferred 21 technologies to industries including pharma industry (TERI Report, 2009). Many educational institutions launched courses at a different level from Diploma to MSc and PhD-level courses including a specialised course on nanobiotechnology. An attempt will be also made to probe into innovations emerging out of international collaboration and analyze the extent to which the FDI is supporting capacity building in this sector.

The present paper will focus on the interactions between the major components of national and international systems of innovation while mapping the Indian nanotechnology innovation system.

2. Analytical framework

The international innovation system is a relatively new framework. Desai (2009, 2012) while discussing international system of innovation and its salient features, argued that with the increasing complexities of emerging technologies like information and communication technologies (IT), biotechnologies (BT) and nanotechnologies and the multiplying convergence between them, a greater need is felt for S&T collaboration. Three phenomena such as emerging technologies (IT, BT, Nanotechnology), the international environment movement and globalisation have co-evolved. He further stressed that globalisation has not only introduced fierce competition but has also forced competitors to cooperate in these areas. Moreover, it is the emerging technologies that are attracting most of the international R&D alliances in recent times. This has further strengthened the linkages between the national and international systems of innovations. There are many components of the international system of innovation, such as inward and outward FDI, migration of knowledge workers, corporate R&D collaborations, institutional linkages, bilateral and multilateral S&T collaborations, international technology trade, international institutional mechanism are gaining greater strength and visibility. Recently, India has emerged as one of the major destinations for the preceding activities (Desai, 2009).

In the preceding context, the present paper has carried out a scientometric analysis for tracking nanotechnology research in India using a data search strategy developed by Mogoutov and Kahane (2007) and patent analysis of nanotechnology patents filed under International Patent Classification B82 in USPTO by using the inventor's address as India for the period 2000-2012.

3. Role of institutions and agencies

Though India was the first country in the world to pass a Scientific Policy Resolution in 1958, India awaited the first explicit Science, Technology and Innovation Policy till January 2013. In the intervening period, India introduced two policy statements, namely, Technology Policy Statement 1983 and Science and Technology Policy, 2003.

However, none of these instruments have specifically focused on the role of naonotechnology. The Science, Technology and Innovation Policy, 2013 has highlighted the following actions such as "seeding S&T-based high-risk innovations through new mechanism" and identified sectors such as "agriculture, telecommunication, water management, energy, health and drug discovery, materials, environment and climate variability and change" for prioritisation of critical R&D areas. These provisions indirectly involve the active role that nanotechnology could play.

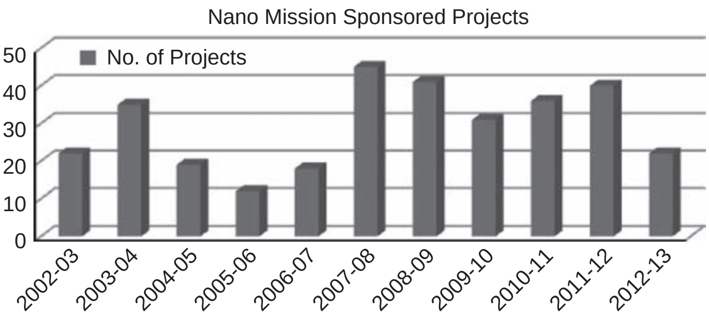
The major funding agency for promoting nanoscience and nanotechnology R&D across the nation are Department of Science and Technology (DST), Department of Biotechnology (DBT), Department of Atomic Energy (DAE), Department of Information Technology (DIT) or major research organisations such as Council of Scientific and Industrial Research (CSIR), Defence Research and Development Organization (DRDO), Indian Council of Medical Research (ICMR) and Indian Space Research Organization (ISRO). The other agencies are the University Grants Commission (UGC) and All India Council for Technical Education (AICTE).

The DST is the nodal agency in the Indian nanotechnology innovation system. It has since 1980s, launched many programmes/schemes to foster R&D for miniature and nanoscale. Such major programmes/schemes are as follows:

- Intensification of Research in High Priority Areas (IRHPAS): A programme launched by DST during sixth Five-Year Plan (1980-1985).
- Committee on Emerging Technologies was set up in 1997 to fund research for three years. SERC also initiated a programme on nanocrystalline material.
- National Programme on Smart Materials (NPSM): a five-year programme funded for US $15 million was launched jointly by five Govt. agencies – DRDO, CSIR, DOS, DST and MIT in the year 2000.
- The NSTI launched by DST started in 2001 focused on various issues relating to infrastructure development, basic research and application-oriented programmes in nanomaterial including Drugs/drug delivery/gene targeting and DNA chips. It gave way to Nano Mission in 2007.
- Nano Science and Technology Mission (NSTM): The Mission on Nano Science and Technology (Nano Mission) – an umbrella programme – was launched in the year 2007 to promote R&D in this emerging area of research in a comprehensive fashion. An allocation of I 1,000 crore (10 billion USD) for five years had been made. The DST is the nodal agency for implementing the Nano Mission. The main objectives of the Nano Mission are – basic research promotion, infrastructure development for carrying out front-ranking research, development of nanotechnologies and their applications, human resource development and international collaborations.

Through NSTI and later Nano Mission, the DST has sponsored many nanoscience and nanotechnology projects across the country in various universities and research centres/laboratories. Since 2002-2003, it has sponsored 321 nanoscience/nanotechnology projects (Figure 1). The further analysis indicates that around 30 per cent such projects were concentrated in central universities/institutes followed by state universities.

The DST established Units on Nano Science, Centres for Nanotechnology, Centre of Computational Materials Science and Thematic Units of Excellence on Computational Material Science in various universities and government research centres/laboratories.



Source: DST Nano Mission Web site (Nanomission.gov.in)

Figure 1.
DST nano-related projects in the period 2002-2013

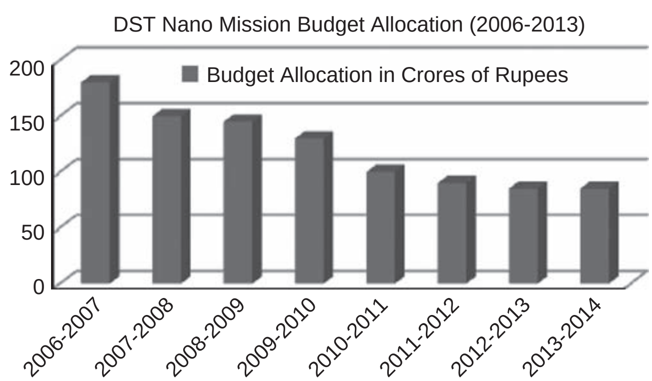
As far as human resource development is concerned, the Nano Mission has launched PG programmes (MSc and MTech in Nanoscience and Nanotechnology) at various universities and colleges all across India and till 2012-2013, 17 such courses were launched in the country.

During the period 2001-2013, The DST has invested approximately INR 965 Crores in Nano Mission since its inception in 2007. The year-wise allocations are as in Figure 2.

Figure 2 clearly points to the fact that the budget allocation for the Nano Mission has decreased considerably. In fact, it is now half of what it was in its inception year 2007. This is a disturbing trend as far as development of an effective Indian nanotechnology innovation system is concerned. It is further observed that the share of Nano Mission's budget in the total DST's budget has declined from around 10 per cent in 2007 to just 3 per cent in 2013 (DST, 2013).

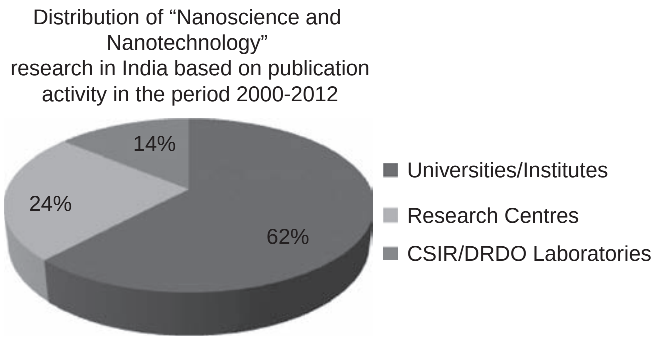
4. Dominant actors

Many scholars describing national innovation systems have emphasised the role that actors play in promoting the generation and dissemination of knowledge, as the main sources of innovation (Nelson, 1993; Lundvall, 1992). A scientometric analysis has revealed that the public universities are the main source of knowledge generation in the area of nanotechnology, followed by government research centres and laboratories (Figure 3).



Source: DST budget documents (analyzed by author)

Figure 2.
DST Nano Mission budget allocation



Source: Thomson Reuter's web of science database (2013; analysed by author)

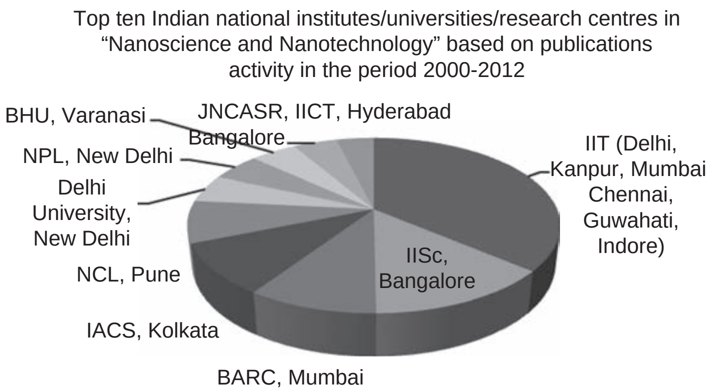
Figure 3.
Nanotechnology-related knowledge generation centres in India

The actors that emerge dominant from the analysis of publications are the national-level centres of excellence/central universities (Figure 4), This implies that the universities play a significant role in publications, but a different picture emerges if the patenting activity is analysed.

Using publication data set, the study found that the top ten knowledge generation actors in India on nanoscience and nanotechnology are either central universities/ national institutes or government research centres/labs (Table I). The government research centres/labs in India actively engaged in nanoscience and nanotechnology research, development and innovation either belonged to CSIR, DRDO, DAE, DST, DEIT, DOS, DBT and DIPP or are deemed university funded by these bodies.

Patent analysis indicates that the government funded research centres/laboratories play a dominant role, followed by the public universities (Figure 5).

Private firms/companies have a one-third share in patent applications in nanotechnology at USPTO. This indicates that as far as nanotechnology-based product/process innovation is concerned, the Indian private industries are not far behind, and they could also play a pivotal role in the future. A survey of 300 nanotechnology-related firms/industries in India has revealed that the majority of them are very large firms (employee strength-wise) followed by small-scale industries (Figure 6).



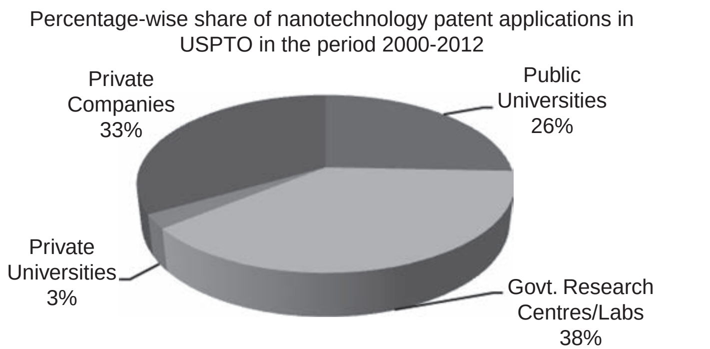
Source: Thomson Reuter's web of science database (2013)

Figure 4.
Top ten nanoscience and nanotechnology R&D centres in India

Table I.
Top ten Indian nano-related knowledge generation centres

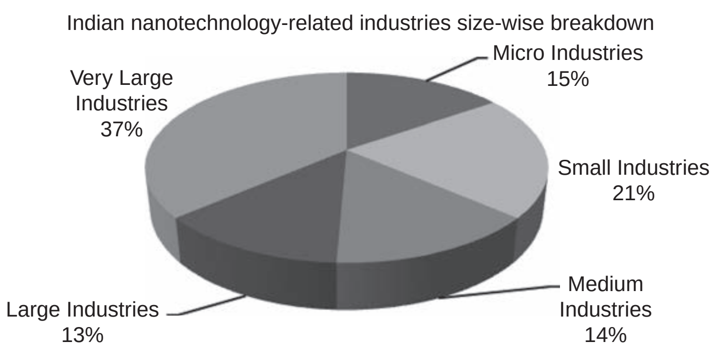
Top ten Indian universities/institutes/research centres	Location
Indian Institutes of Technology	At 15 cities
Indian Institute of Science	Bangalore
Bhabha Atomic Research Centre	Mumbai
Indian Association for the Cultivation of Science	Kolkata
National Chemical Laboratory	Pune
University of Delhi	New Delhi
National Physics Laboratory	New Delhi
Banaras Hindu University	Varanasi
Jawaharlal Nehru Centre for Advanced Scientific Research	Bangalore
National Institute of Technology	At 30 cities

Source: Web of science (2013)



Source: Thomson Innovation patent database (2013; analysed by author)

Figure 5.
Share of stakeholders in nanotechnology patent share



Source: Author's survey (2013)

Figure 6.
Indian nanotechnology industry classifications

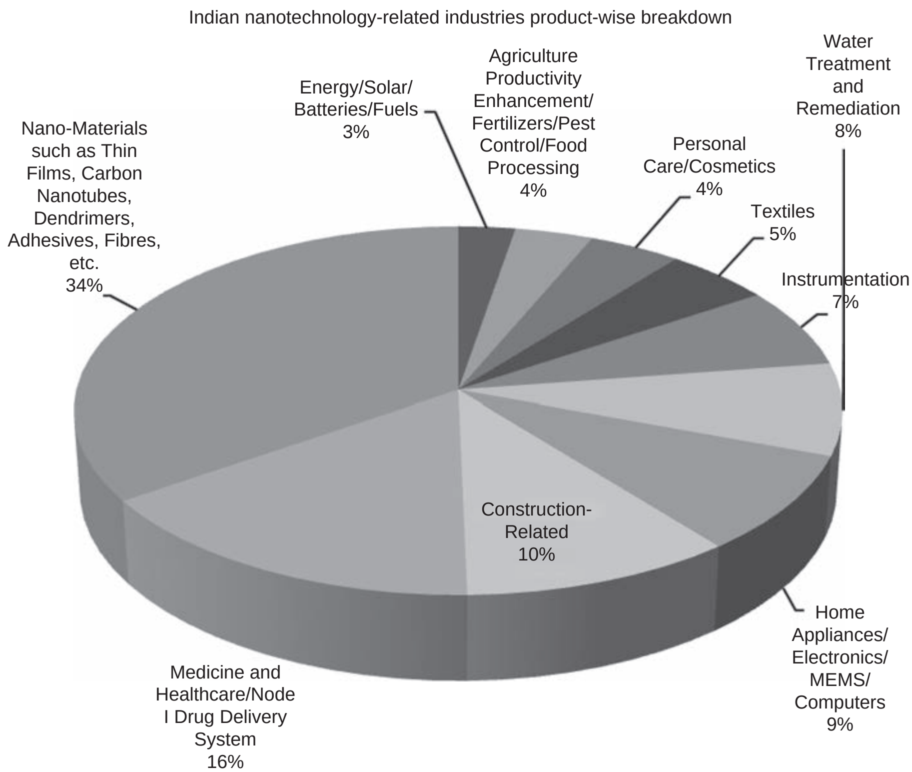
This demonstrates that the nanotechnology-based product development and commercialisation is dominated by industries that are already well-established entities. These firms have incorporated nanotechnology in their in-house R&D to produce and launch various finished products.

It is to be noted here that contribution of Indian firms to R&D has been increasing, and it accounted for 34 per cent of total GERD (Gross Expenditure on R&D) in 2007 compared to only 19 per cent in 2002 (OECD, 2012).

Further analysis reveals that most of the new firms are micro and small-scale firms and they are mostly into developing intermediary nano-materials, followed by healthcare/medicine-related product developments (Figure 7).

The present study has also observed that the high-performing research centres/labs either belong to CSIR or to DRDO or are autonomous research institutes set up by the DBT, Department of Industrial Policy and Promotion, Ministry of Chemicals and Fertilisers, Ministry of Communication and Information Technology, DAE and Department of Space. Hence, this reveals a significant role played by the institutions and the public sector in setting-up centres of excellence in nanotechnology all across the country.

Furthermore, the venture capital funding in Indian nanotechnology industries is only slowly emerging. Though, the actual data on the scale of venture capital funding in Indian nanotechnology-based industries might not be available at present, there are reports of a few VC firms funding the nanotechnology-based start-up companies. Globally, the amount of nanotechnology funding coming from venture capital was as low as only 4 per cent of total global funding in 2010 (Lux Research, 2011). This indicates that only the established firms promote the major proportion of nanotechnology innovations.



Source: Author's survey (2013)

Figure 7.
Indian nanotechnology industry focus areas

In this backdrop, a recent announcement by the central government's Department of Scientific and Industrial Research in its plan document for the period 2012-2017, holds significance. It envisages supporting equity in knowledge-based start-ups with SIDBI Venture Capital Ltd. A fund of I 300 crores has been set aside for the purpose (DSIR, 2012).

5. Inter-linkages and collaborations

The analysis of publications/co-authorship data of top ten Indian actors reveals that the Indian universities (central, state, private and deemed), government research centres/labs, Indian industries and foreign universities/research centres are involved in some sort of collaboration with each other. These collaborative forms are as follows:

- Central University/National Institute – Central University/National Institute collaboration.
- Central University/National Institute – Govt. Research Centre collaboration.
- Central University/National Institute – State University collaboration.
- Central University/National Institute – Indian Industry collaboration.
- Indian Central University/National Institute/Govt. Research Centre-Foreign University/Research Centre collaboration.

The present study analysed the various forms of inter-linkages and collaborations of Indian Institute of Science (IISc, Bangalore) as demonstrated in Tables II, III, IV and V:

- IISc – Central University/National Institute collaboration.
- IISc – Govt. Research Centre collaboration.
- IISc – State University collaboration.
- IISc – Indian Industry collaboration.

Table II. Top collaborating public central universities with IISc

Top collaborating public central universities with IISc	Location
Indian Institutes of Technology	Many cities
University of Hyderabad	Hyderabad
National Institutes of Technology	Many cities

Source: Web of science (2013)

Table III. Top collaborating public research centres with IISc

Top collaborating public research centres with IISc	Location
Jawaharlal Nehru Centre for Advanced Scientific Research	Bangalore
Indian Association for Cultivation of Science	Kolkata
SN Bose National Centre of Basic Sciences	Kolkata
Bhabha Atomic Research Centre	Mumbai
Central Electrochemical Research Institute	Karaikudi
Defence Research and Development Lab	Hyderabad
Tata Institute of Fundamental Research	Mumbai

Source: Web of science (2013)

5.1 International collaboration

While entering into international collaboration, the national actors of the collaborating countries that get transformed into international actors and integral part of the international innovation system share the advantages and disadvantages of the hierarchical international order (Desai, 1997). It is in this context that the Indian inventor's contributions in international nanotechnology R&D endeavours are analysed.

The DST has been the nodal agency for coordinating bilateral/multilateral collaborations efforts. As far as international collaborations in the field on nanoscience and nanotechnology research, development and innovation is concerned, DST has launched many bilateral joint-research projects with more than 25 countries and multilateral research projects with regional/multilateral groupings such as European Union, BRICS (Brazil, Russia, India, China) and IBSA (India, Brazil and South Africa). There has been a remarkable increase in the investment made by the DST amounting to almost ten times in the period 2006-2012 (Figure 8).

In terms of the number of research projects as well, the increase was almost three times in the same period 2006-2012 (Figure 9).

These international collaborative projects cover a wide range of nanoscience and nanotechnology basic and applied research areas having diverse applications such as in:

(1) healthcare/medicine/drug delivery;

(2) sensors;

(3) energy Storage in batteries;

(4) solar energy;

(5) fuel cells; and

Top collaborating public state universities with IISc	Location
Bangalore University	Bangalore
MS Ramaiah Institute of Technology (VTU)	Bangalore
Sri Venkateswara University	Tirupati
Tumkur University	Tumkur
University of Madras	Chennai
BMS Institute of Technology (VTU)	Bangalore
Kuvempu University	Shimoga

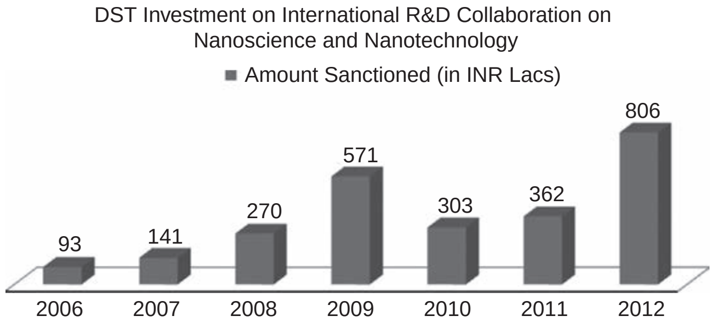
Source: Web of science (2013)

Table IV. Top collaborating public state universities with IISc

Collaborating industries with IISc	Location	Area of research
Bharat Heavy Elect Ltd	Bangalore	Nano coatings, thin films
Datar Switchgear Ltd	Nashik	Nano structure alloy
IBM R&D Centre	Bangalore	Transistors
Indian Oil Corp Ltd	Faridabad	Nano particles in diesel engines
TATA Steel	Jamshedpur	Nano structure steel
GE India	Bangalore	Nano composite alloy
NED Energy Ltd	Hyderabad	Batteries, cells

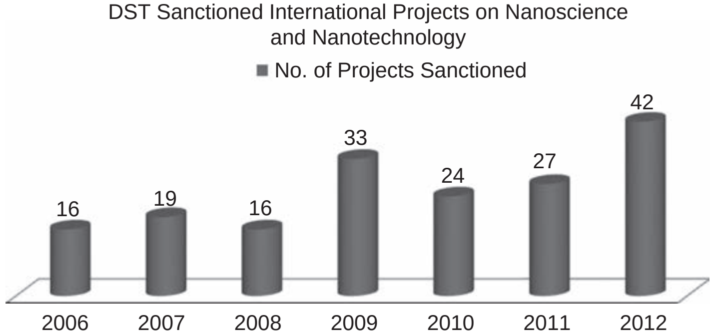
Source: Web of science (2013)

Table V. Collaborating industries with IISc



Source: DST international cooperation division (analyzed by author)

Figure 8.
DST investment on international R&D collaboration



Source: DST international cooperation division (analyzed by author)

Figure 9.
DST sanctioned International projects

(6) other areas of use of nano-materials such as thin films, carbon nanotubes, nano composites.

India collaborates with several countries in this field of nanoscience and nanotechnology research and has attracted collaboration mainly from the most developed countries. This fact is evident in Table VI, which provides a list of top 20 collaborators. Most of the top 20 countries that are collaborating with India in this field are developed countries, with the exception of a few examples, including Brazil, China and Saudi Arabia.

Indian universities/research centres collaborate with foreign universities/research centres/industries. The IISc Bangalore has collaboration with several foreign universities/research centres (Table VII).

These institutional and human resource collaborations are indicative of an increasing need for international S&T cooperation in emerging technologies.

6. Conclusion

While mapping the Indian nanotechnology innovation system, the following observations have emerged:

(1) In India, nanotechnology-based industries are yet to emerge as a dominant sector. This is despite the fact that a series of government interventions is discernible in various programmes since 1980s.

Developed countries	Developing countries
USA (1)	Saudi Arabia (10)
Japan (2)	China (11)
Germany (3)	Brazil (18)
South Korea (4)	South Africa (19)
France (5)	
England (6)	
Singapore (7)	
Canada (8)	
Italy (9)	
Taiwan (12)	
Australia (13)	
Sweden (14)	
Spain (15)	
Portugal (16)	
Ireland (17)	
Switzerland (20)	

Source: Thomson Reuter's web of science database (2013)

Table VI. Top 20 collaborating countries with India with their ranks in bracket

Top collaborating foreign university/research centre with IISc	Country
University of Johannesburg	South Africa
Tohoku University	Japan
University of Cent Florida	USA
Rensselaer Polytech Institute	USA
Caltech	USA
Chungbuk National University	South Korea
University of California Santa Barbara	USA

Source: Thomson innovation patent database (2013; analyzed by author)

Table VII. Top collaborating foreign university/research centre with IISc

(2) It is clear from the preceding that the public universities are the main source of knowledge generation in the area of nanotechnology, followed by government research centres and laboratories; whereas its application in terms of patenting is concerned, the public research labs play a more dominant role in India.

(3) The private sector has revealed great potential and could play a significant role in the future.

(4) India has attracted collaboration mainly from the developed countries and only a few developing countries figure as the top collaborators.

(5) It is also evident from the patent analysis that Indian inventors were part of the research teams of around ten countries involved in international patents on nanotechnology.

(6) Recently, India has emerged as one of the major destinations of inward and outward FDI, migration of knowledge workers, R&D collaborations, institutional linkages, inventor collaborations, technology intensive export and international institutional engagement.

In the context of the foregoing, it is clear that the interactions between the national and international innovation systems can no longer be ignored.

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