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# Emerging technologies in India: Developments, debates and silences about nanotechnology

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In the last decade nanotechnology entered the policy arena as a technology that is simultaneously promising and threatening, and with a similar Janus-like face, nanotechnology entered the development agenda. How does a developing country like India deal with nanotechnology? Combining a quantitative and qualitative approach, this paper outlines the developments, discussions, and silences concerning nanotechnology in India. The nanotechnology landscape in India is dominated by government initiatives. Government investments led to a steady rise in global publication rankings, scientific collaborations and the number of institutions involved. This growth is mainly rooted in fundamental research and public research institutes. Industry involvement and patenting activity are at a nascent stage and developing slowly. Issues that were raised in the Indian context relate to funding, capacity, commercialization, regulation of risks, and the distribution of benefits. Nanotechnology is positively viewed across the board, with notable silences on ethical issues and the relation to the public.

*Keywords: India; emerging technologies; nanotechnology; governance; regulation.*

## 1. Introduction

Emerging technologies pose several pertinent challenges. Emerging technologies can be defined as science-based technologies that are characterized by novelty, recent high-growth, and potentially broad impacts (Cozzens et al. 2010). In the past two decades it has become increasingly clear that this combination of characteristics can make standard forms of decision-making inadequate. For instance, established forms of risk assessment may not be applicable to the new technology, the boundary-crossing nature of emerging technologies may make it impossible to rely on existing disciplinary or institutional divisions of labor, and the future effects of the technology are sometimes fiercely disputed, giving rise to long-standing societal controversies.

Although countries worldwide are drawn towards the 'windows of opportunity' that the emerging technologies are promising to open, it has been observed that the response of countries to emerging technologies and its societal embeddings varies (Swierstra and Rip 2007). For instance, it is generally thought that whereas the USA has a more adversarial style of decision-making, European countries are characterized by a consensual style (Brickman et al. 1985; Löfstedt and Vogel 2001). Furthermore, the response to emerging technologies and its societal embeddings also varies through time. In the European context, for instance, a decline in trust following several scandals in high-technology sectors has led decision-makers to attempt to include actors other than the government in the decision-making process, a change also known as a shift from government to governance. Although this illustrates that such responses to emerging technologies are highly situated, they have almost exclusively been considered from the perspective of Europe or the USA. This paper shifts the geographical focus and explores the developments, debates, and silences regarding emerging technologies in India. More specifically, this paper investigates the emergence of nanotechnology in India.

Nanotechnology is usually conceptualized as the understanding and control of matter at the nano-scale. At this scale some materials gain radically new properties. The application of these properties to innovative products and processes is said to have such pervasive consequences that the 21st century is already being heralded as the 'nano-century' (Dhawan et al. 2009). Since the beginning of the last decade several commentators have also drawn attention to the need for countries in the Global South to engage with this new technological wave. Many authors have argued that an early engagement in nanotechnology may not only give rise to various pro-poor applications, it should also prevent this new technological wave from deepening rather than bridging the global divide (Brahic 2004; Maclurcan 2009). From the early 2000s onwards, numerous countries in the Global South, including India, have taken up this call. The Government of India has been systematically investing in nanotechnology since 2001. However, whereas nanotechnology has given rise to sustained academic debate in Western Europe and the USA, very little is known about the situation in India. Therefore, this paper explores the way in which India deals with the challenges raised by nanotechnology.

Rather than exclusively focusing on a limited set of pre-defined challenges, we seek to understand the framing of challenges raised by nanotechnology. This is of crucial importance in investigating the situated response to emerging technologies and their societal embedding because of the highly contextual nature of such challenges. For instance, in the case of biotechnology it has been shown that, whereas the USA regulatory response emphasized human health and environmental impacts, the particularities of the Indian situation led to the inclusion of the economic situation of marginal farmers (Freeman et al. 2011). Whereas the emphasis on human health and environmental impacts was well-suited to the North American interests in biotechnology, the Indian context gave rise to challenges that differed significantly. Therefore not only the question of how challenges are dealt with gains importance, which issues are deemed important in the first place should also be considered. In line with this exploratory objective we do not restrict our focus to the output achieved by various actors. In order to capture wider discussions pertaining to nanotechnology we cast our nets wider to include actions by other social groups such as industry, civil society, and the media. Rather than focusing on either public discussions or quantitative indicators, we combine both sets of data in order to provide a more comprehensive picture of the way in which nanotechnology is dealt with in India.

Besides creating a better understanding of the relation between nanotechnology and society in India, such an overview of developments relating to nanotechnology may be well of use to the actors in the field. Despite the potential importance of nanotechnology, debates and commentaries on nanotechnology in India have been rather scattered. Various Indian commentators have identified a lack of an overview as a major impediment to the development of nanotechnology. For instance Ajay Sood, professor of physics at the Indian Institute of Science in Bangalore said:

> . . . an information map on interested industry and academics is very much needed; an information platform that is easily accessible and can be updated. (Padma 2008)

Furthermore, as Srivastava and Chowdhury (2008b) note:

> Given the pace of development of nanotechnology in India, such a structural gap creates impediments in establishing regulatory oversight of environmental, health and safety risks in a comprehensive manner.

This paper may serve as a first step towards bringing together information about nanotechnology developments in India.

## 2. Nanotechnology issues

Nanotechnology is a quintessential example of an emerging technology. Nanotechnology is usually defined as the understanding and control of matter at the nano-scale, roughly in the range 1–100 nanometers, with one nanometer being $10^{-9}$ meter (National Nanotechnology Initiative 2011). By comparison, when writing on A4 paper:

> . . . the dot of this 'i' alone encompasses about 1 million nanoparticles. (Allianz and OECD 2005: 3)

Several breakthroughs in microscopy in the 1980s, most notably the development of the scanning tunnelling microscope by Gerd Binnig and Heinrich Rohrer, enabled scientists to visualize and manipulate materials at the nano-scale in an unprecedented manner. At this scale, some materials acquire all sorts of new characteristics due to a combination of scale effects and the operation of quantum laws. The expectation that these characteristics can be used in a wide range of innovative applications led governments and industries around the world to invest in nanotechnology R&D. The expectations of the merits of nanotechnology rose to enormous heights, with the American government heralding it as the bringer of the 'Next Industrial Revolution' (White House 2000; Selin 2007).

Ever since the inception of the American National Nanotechnology Initiative in 2000, nanotechnology has been subject to debate. Most of these debates, however, are situated in Western Europe and North America and India does not feature prominently in reflections about these developments and debates. These Western European and North American debates can provide a background against which to situate developments and debates in India. For instance, several of these issues have been captured by Kjölberg and Wickson (2007) in their attempt to map the social science literature on nanotechnology. The extensive volume on the societal implications of nanotechnology edited by Roco and Bainbridge (2007) also provides some useful leads.

The governance of nanotechnology is a challenge that is addressed in what is perhaps the largest sector of social science research. In its most general form the question here is how particular countries, groups, or actors can facilitate the responsible development of nanotechnology. In the wake of the enormous expectations it has, for instance, been said that taking advantage of the transformative potential of nanotechnology requires several changes in R&D policies and business models (Roco 2005). In particular, the boundary-crossing nature of nanotechnology has given rise to several issues. Because materials at the nano-scale are not confined to one particular scientific field or industrial sector, nanotechnology is expected to have an impact that crosses many existing disciplinary and institutional boundaries.

Another major challenge that nanotechnology has raised across the world is the potential risk of nanotechnology to human health and the environment (Maynard et al. 2006; Royal Society and Royal Academy of Engineering 2004). This has been subject to substantial discussions in both the scientific and popular media. The novel characteristics of nanoparticles that give room to such high expectations may also entail new risks for health and the environment. The observation that the risks associated with nanotechnology are to a large degree characterized by uncertainty has been of particular interest. Although some studies have demonstrated that specific nanoparticles can pose risks for human health and environment (see Oberdörster et al. (2007) for an overview), both the extent to which they inflict harm, which nanoparticles do so, and how they do so thus far remains largely unknown. This gives rise to discussions about issues such as: finding appropriate methods for testing, labelling of nanotechnology products, and applying the precautionary principle (Dhawan et al. 2009; Mehta 2004; Weckert and Moor 2007).

Substantial attention has also been paid to the inclusion of new actors by governments around the world. Quite some attention has been paid to the relations between actors from industry, government, and science and also the potentially problematic relationship between nanotechnology and what has been called 'the public' has been the subject of debate. Several commentators have proposed to proactively deal with this relation, be it to convince the public of set priorities or to allow the public to have a say in the direction of nanotechnology development. Several countries have initiated such activities under headings such as: public participation, deliberation, hybrid forums etc. (Pidgeon and Rogers-Hayden 2007; Rogers-Hayden and Pidgeon 2007; Bowman and Hodge 2007; Stø et al. 2010).

Related to this, several discussions have focused on the potentially negative ethical consequences of nanotechnology. For instance nanotechnology may be used in warfare, may invade people's privacy, or may impinge on the relationship between human beings and technology. The establishment of the journal *NanoEthics* in 2007, entirely dedicated to discussing social and ethical issues for nanotechnology, signals that a community of researchers is emerging around these themes.

Some years after the USA initiative, several commentators (mainly based in Western countries) also started drawing attention to the application of nanotechnology to non-Western contexts. One major issue that has been raised with respect to developing countries is that nanotechnology can aggravate global inequalities. Negatively phrased, developing country engagement in nanotechnology is said to be required in order to avoid that this new technological wave deepening, rather than helping to bridge the global divide. In this context, some authors have already spoken of a newly emerging 'nano-divide' (Brahic 2004; Maclurcan 2009). Taking a more positive perspective, studies such as those by Mnyusiwalla et al. (2003), the Meridian Institute (2005) and Salamanca-Buentello et al. (2005) have focused on the benefits of particular nanotechnology applications. Especially in the fields of water, energy, and health, it has been pointed out that nanotechnology can contribute to the creation of cheaper and more efficient technologies that can help the poor, such as: improved water filters, energy storage systems, solar powered electricity, and portable diagnostic tests (Mnyusiwalla et al. 2003; Meridian Institute 2005; Salamanca-Buentello et al. 2005).

Besides discussions on the incentives for developing countries to engage in nanotechnology development, some commentators have focused on more specific issues that nanotechnology developments may bring about for developing countries. Schummer (2007) for instance points out the potentially reverse effects of nanotechnology developments on material demands and consequently on developing countries' export of raw materials. Properties at the nano-scale may be used to imitate the properties of rare minerals, thus affecting the export rates of their main producers. Others, such as Invernizzi and Foladori, have tempered the enthusiasm for nanotechnology as a technological fix and have instead drawn attention to the importance of the social context in which it develops (Foladori and Invernizzi 2005; Invernizzi and Foladori 2005; Invernizzi et al. 2008).

These are some examples of issues that have been raised as crucial to either taking advantage of nanotechnology's potential benefits or to avoiding being hit by its potential drawbacks. It should be stressed that, even within the West, only some of these issues have been interpreted as problematic. For instance the European context has hardly witnessed any concern that nanotechnology might replace the export of raw materials and the discussion on nanotechnology labelling has been more prominent at the European Union level than in particular European member states. Furthermore, in those places where the issues discussed above have been addressed, these have been dealt with in many different ways, as is evidenced by the large body of social science literature on nanotechnology (Kjölberg and Wickson 2007). This discussion is by no means comprehensive but gives an impression of the type of issues that nanotechnology may bring about and provides the backdrop against which to situate developments and debates in India.

## 3. Research methodology

Our approach towards studying the Indian response to nanotechnology is twofold. First, we conducted a quantitative analysis, primarily based on bibliometric indicators constructed from research papers and patents. Publication data was retrieved from the Science Citation Index Expanded (SCI-E), accessed via the Web of Science. Using this database gives a good indication of the state of nanotechnology research in India, even though several Indian journals are not included in the SCI-E. The SCI-E covers data from over 8,000 leading scientific and technical journals across 174 disciplines and covers over 100,000 conference proceedings in every subject area. To capture nanotechnology publications, the search string defined by Kostoff et al. (2007) was applied in the title and/or abstract field. A keyword analysis was done using the keywords attached to each article and an analysis of the co-occurrence of most active keywords (co-word analysis) was undertaken using the Bibexel software.

Patent data was retrieved from the Delphion database, containing the world's most comprehensive collection of patent data, from major patent authorities, specific nations and proprietary sources. US Patent and Trademark Office (USPTO) grants and applications were accessed through this database. Indian Patent Office (IPO) grants and applications were captured through <http://www.India.bigpatents.org>. Not all products are patented and not all patents yield products. But patenting activity does provide a tangible indication of the proximity of nanotechnology products to the market. In addition, just as with publications, the involvement of various actors and linkages amongst them can be revealed through the bibliometric indicators. Nanotechnology is classified by class 977 in the USPTO. This classification was used for downloading patent data from the USPTO. Due to searching limitation in the Indian patent database, an elementary search string 'nano*' was used for extracting nanotechnology patents. 'Nano*' defines all prefixed terms and had been used earlier in harvesting nanotechnology publications (Tolles 2001; Meyer 2001).[1] Finally, a newspaper clipping service called Indian Business Insight Database Products was used to shed light on nanotechnology products and processes that had been developed. From 1993 to the present, this database covers over 297 newspapers and magazines primarily from Indian and Asian businesses.

Although these sources provide us with relevant information about the state-of-the-art publishing and patenting activity of scientists and engineers based in India, they can only provide us with a limited understanding of the issues that nanotechnology gives rise to and the way they are dealt with. Therefore, we also conducted a qualitative analysis in which we attempted to map the various discussions on nanotechnology in India.

Several social science databases were searched in order to obtain a grasp of the issues concerning nanotechnology discussed in the Indian context. We searched for nanotechnology and India using the Web of Knowledge, EBSCOHOST, and Google Scholar. Web of Knowledge includes over 12,000 journals and book series and EBSCOHOST integrates over 300 databases and has indexed over 13,000 journals and magazine. Both databases are widely used as indicators for research output although they are biased towards English-language publications. Google Scholar covers a wide range of online journals but its exact coverage is not made public. Technical documents (for instance with India in the address line) were excluded. In all our queries we consistently used the deliberately broad terms 'nano*' and 'India'. Although this forced us to filter out numerous hits dealing with either iPod Nano or Tata Nano, it ensured that we captured the diverse range of names that are given to nanotechnology developments, such as 'nanotechnologies', 'nanotech', 'nano-scale research' and simply 'nano'. Also this allowed us to capture debates about nanotechnology in India that may diverge from those taking place in Western countries, as described in Section 2.

Naturally, nanotechnology is not only framed in scholarly articles. Such scholarly work needs to be complemented by sources from other domains. Sources such as policy documents and newspaper articles are likely to be more prominent forums in which the challenges posed by nanotechnology are discussed. Therefore we added sources derived from an extensive Google search for nanotechnology in India as well as sources derived from a snowball method: we systematically pursued references found in sources derived from the databases and search engines mentioned above.

These search efforts resulted in a large number of sources that diverged both in the nature of the documents and the sources of origin. Besides social science articles and policy documents we processed various types of reports, opinion pieces, websites and newspaper articles. These were produced by government officials, scientists, social scientists, employees of non-governmental organizations (NGOs) and industries. The sources were processed in two ways. First, we used the qualitative analysis to derive qualitative information about the developments mapped in the quantitative analysis, for instance about the objectives of government policies, the specific actors involved in collaborative research, the organizational structure, and the distribution of research funds. Secondly, we used these sources to map the issues that were raised amongst heterogeneous actors throught time. Close reading the sources allowed us to map the various discussions in which the challenges that nanotechnology developments may give rise to are framed by particular actors. The obvious downside of this approach is that it is very time-consuming. Yet arguably, it provides a better view on what issues emerge and how they are dealt with than by exclusively relying on scholarly papers.

In the following we will present the results in two sections. Section 4 outlines the developments pertaining to nanotechnology in India. Publication statistics, patent data, and information about the geographical spread of nanotechnology in India are shown. Information is also provided about the number of products, (international) collaborations, organizational structures and actors involved. Section 5 discusses those challenges which are raised in India. It shows that the discussion about challenges posed by nanotechnology in India is structured along five lines: funding; commercialization and science–industry linkages; regulation of risks; capacity; and the distribution of benefits.[2]

## 4. Developments in India

The Government of India is playing a key role in building research capacity in nanotechnology in terms of funding, establishing scientific and technological infrastructure and developing human skills. It has been investing in nanotechnology as a distinct area of research since 2001. In that year the Nanoscience and Technology Initiative (NSTI) was launched as a mission mode programme in the Tenth Five Year Plan (2002–7) with a budget of approximately 60 million rupees.[3] The Department of Science and Technology (DST) has been acting as the nodal agency and continued to play this role with the launch of the successor of the NSTI, called the Nano Mission, with a budgetary allocation of 10 billion rupees for five years (Kothari 2008). The total budget proposed for various schemes and programmes run by the DST in the Eleventh Five Year Plan (2007–12) was 193 billion rupees. Influential scientists such as C. N. R. Rao and the former Indian President, Abdul Kalam, have been instrumental in mobilizing this extensive government support for nanotechnology. As Chandra and Narasimhan (2005) describe:

> . . . since his appointment as the President of the country, Dr. Kalam has been campaigning for programs to expedite the development and commercialization of nanotechnology in India. (Chandra and Narasimhan 2005: 289)

The main driving force has been the urge to be at the forefront of this technological wave, so as 'not to miss the bus'. Right from the start government priority has been to create a strong institutional base, infrastructure support, and skilled manpower to develop nanoscience and technology (Department of Science and Technology 2007). One way to achieve this has for instance been the creation of a series of centres of excellence (see Fig. 1). Although there is a large inward focus towards developing nanotechnology within the sphere of public institutions, under the Nano Mission a more outward-looking focus was adopted that laid more emphasis on applications. For instance, public–private partnerships have received more attention and members from industry were included in the Nano Mission organization which was earlier solely dominated by scientists from the public research institutes.

Following the lead of the DST, a host of other government agencies has since stepped in. The Department of Information Technology and the Defense Research and Development Organisation have dedicated specific programs for nanotechnology and the Department of Biotechnology, Department of Atomic Energy, Council for Scientific and Industrial Research, Indian Council for Medical Research and the Ministry of New and Renewable Energy are also funding initiatives in nanotechnology R&D, although information on the precise number of these investments is not available. India has also entered into bilateral nanotechnology programmes with the European Union, Germany, Italy, Taiwan and the USA. Among the tangible outcomes was the creation in 2004 of a National Centre for Nanomaterials in collaboration with the USA, Germany, Japan, Russia, and the Ukraine. Although to our knowledge the agricultural ministries have not yet taken any formal steps to engage in nanotechnology, in April 2008 the Planning Commission of India recommended that nanotechnology become one of six areas for investment as a means of boosting agricultural productivity (Sreelata 2008). Also several state governments (e.g. Karnataka, Gujarat, Tamil Nadu, Haryana, Andhra Pradesh and Himachal Pradesh) have taken initiatives to support nanotechnology developments.

Although making a slow start, companies are starting to become involved in nanotechnology R&D. The Confederation of Indian Industry has taken initiatives to increase industry involvement in nanotechnology and during our qualitative research we identified over 50 companies that were said to be involved in nanotechnology in India, including business consultants, distributors of instruments, conference organizers, firms offering education to industries, as well as large industrial consortia and companies focusing on drug delivery systems, software products, and the manufacture of nanomaterials (for some inexhaustive overviews see Agoramoorthy and Hsu 2010; Varadarajan 2008; Ramani et al. 2011; Nanowork.com 2011). Companies like Tata Steel, Tata Chemicals, Mahindra and Mahindra, Nicholas, Piramal and Intel are estimated to have invested over 1.2 billion rupees in nanotechnology R&D (Dutta and Gupta 2006). Two large Indian companies, Reliance and Tata

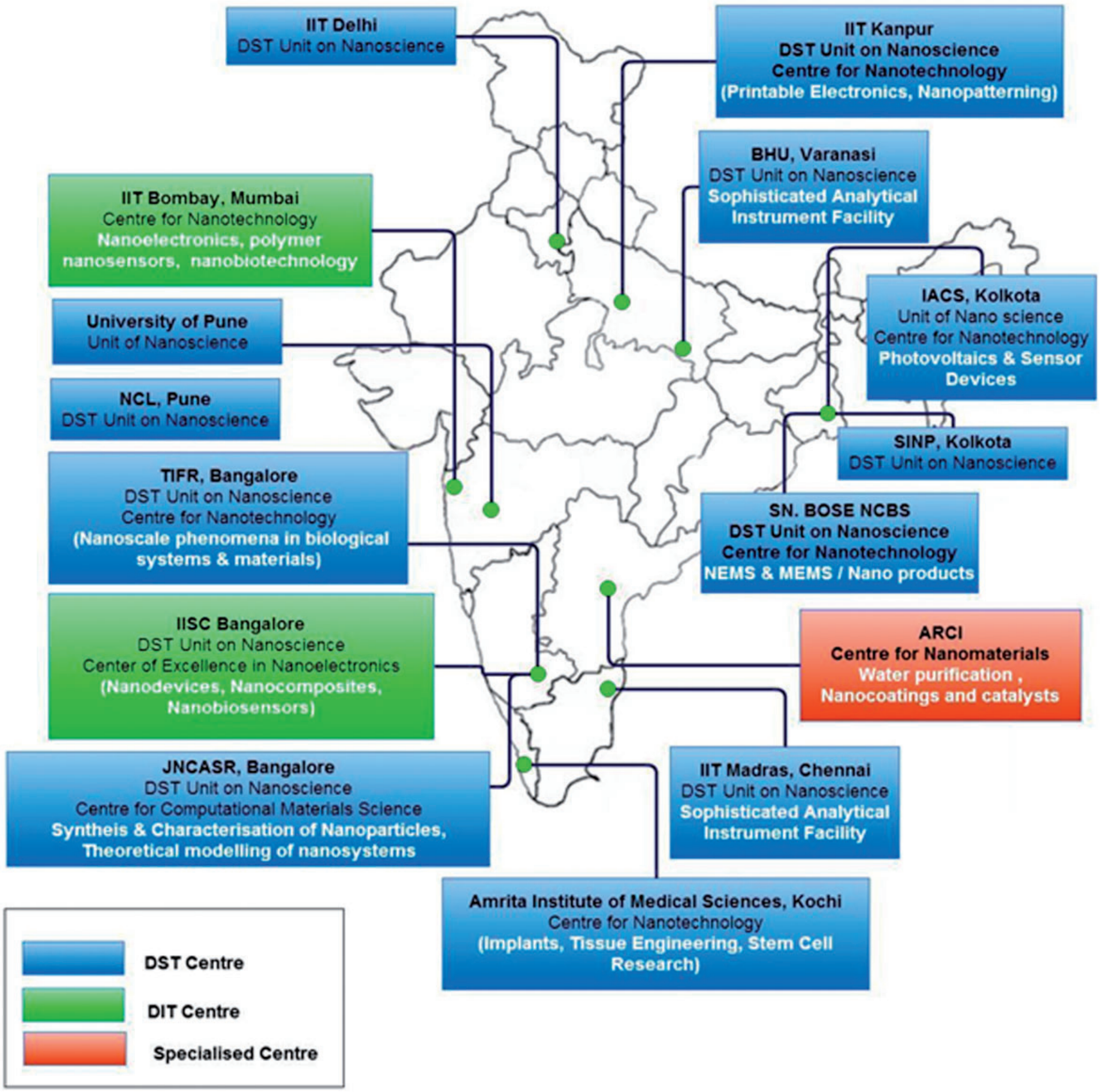


**Figure 1.** Nanotechnology centres of excellence in India.

Chemicals, have set up nanotechnology R&D centres in Pune. Unfortunately, the total investments made in nanotechnology, or the nature of the involvement of industry, are hard to estimate.

Although societal actors have been generally absent, one NGO entered the scene in 2007. Funded by the International Development Research Centre in Canada, The Energy and Resources Institute (TERI) has since deployed a series of activities in the field of nanotechnology. Through a number of publications and workshops they have drawn attention to issues such as governance, toxicology, and capacity building (The Energy and Resources Institute 2011).

In terms of regulation the Government of India has not been very active. A major category of risk related areas come under the responsibility of Ministry of Environment and Forest (MOEF) but none of the MOEF acts and legislation explicitly identify nanoparticles as a potential hazard. As was mentioned above, the DST acts as the nodal agency for nanotechnology in India but its mandate is to promote nanotechnology. Perhaps unsurprisingly then, there is no reference whatsoever to risks or other potential negative impacts of nanotechnology in the NSTI or Nano Mission. Yet it was the Nano Mission that announced the creation of a nanotechnology regulatory board in January 2010. Following this announcement

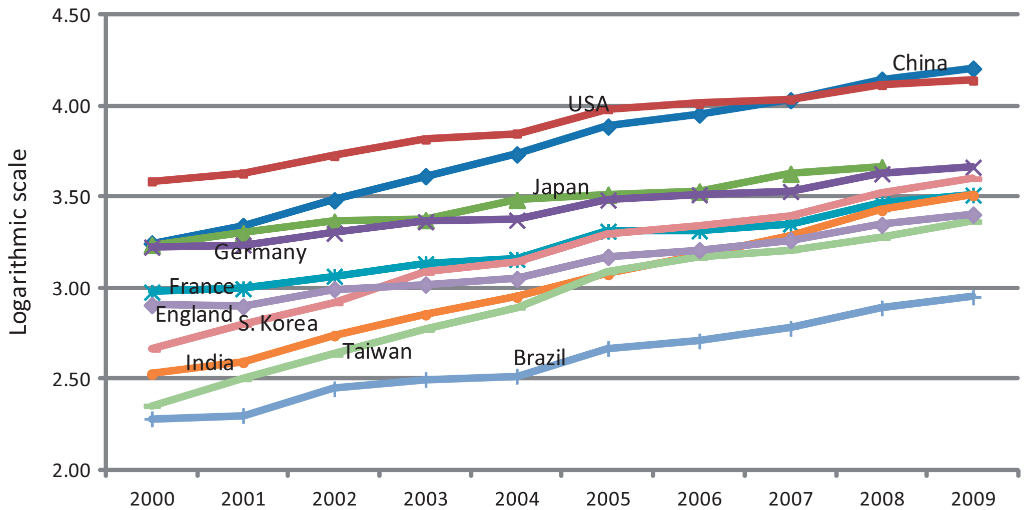


**Figure 2.** Publication activity of key OECD and emerging economies in period 2000–9.

the DST created a committee on risks and ethical issues in the fall of 2010 but their agenda and activities have remained unclear and nothing substantial has yet emerged.

More activities can be discerned with respect to risk research and standardization. Recently some studies have been initiated by the DST and its various sister departments on the environmental, health and safety aspects of nanotechnology, executed by institutes such as the Indian Institute of Toxicology Research and the National Institute of Pharmaceutical Education and Research. Along with these institutes, until the turn of the last decade it was TERI that drew most attention to environmental, health and safety issues, and ethical, legal and social issues related to nanotechnology (The Energy and Resources Institute 2008, 2009b, 2010). As for standardization, the Bureau of Indian Standards accepted an invitation to participate in the technical committee on nanotechnology standards of the International Organization for Standardization. Several studied have consequently been taken up but progress remains unclear.

Investments in nanotechnology research have had visible results in terms of publication output. In the period 2000–9, India published 13,092 papers in nanotechnology, of which 25% emerged in 2009 (see Fig. 2). India accounted for 2% of the total number of papers in 2000 (global rank 17th) and in 2009 it accounted for 5% of the total number of papers (global rank 6th) in nanotechnology. Consistent with the findings of previous studies (Lui et al. 2009; Mohan et al. 2010), we observe a steady rise in publication output, particularly since 2007. One observes that the Indian activity matches with advanced OECD countries in later years, even surpassing England in 2007. Following this observed increase in publications, foreign commentators have labelled India an ‘emerging nanopower’ (Hullmann 2007). This strong Indian presence in nanotechnology publications is also reflected in the relatively high number of Indian researchers that act as editors to nano-titled journals (Braun et al. 2007).

Indian researchers are actively publishing in journals with reasonably good impact factors (IFs). Among high IF journals, Indian researchers have published 249 papers in the *Journal of Physical Chemistry C* (IF = 4.22), 243 papers in *Physics Review B* (IF = 3.47), 232 papers in the journal *Nanotechnology* (IF = 3.137), during the period 2000–9. In terms of citation scores Indian researchers perform less well. There were only three papers from India were among the top 1% cited papers in 2000 and six papers in 2005. In 2009, India made its presence more visible with 26 of its papers among the top 1% cited papers in nanotechnology. Yet despite this improvement, countries with much lower outputs in terms of numbers of publication such as Singapore, Switzerland, Spain are positioned above India.

An increase in the number of institutions involved can be observed: 423 institutes were involved in publishing in 2000 whereas 1,349 institutions were involved in 2009. Overall, the academic institutions and research laboratories (mainly the laboratories of the Council for Scientific and Industrial Research) that already had good reputations were most prolific. As was also found by others (Lui et al. 2009; Arunachalam and Viswanathan 2008), the Indian Institute of Science is the Indian research institute that is the most active in publishing in the field of nanotechnology. During the period 2000–9 the Indian Institute of Science published 1,004 papers, followed by IIT Khargapur (830 papers), National Chemical Laboratory (734 papers) and Indian Association of Cultivation of Science (734 papers). As for individuals, earlier research has found that the most successful Indian researcher is C. N. R. Rao (Mohan et al. 2010), ‘India’s star nanoscientist’ (Bound 2007).

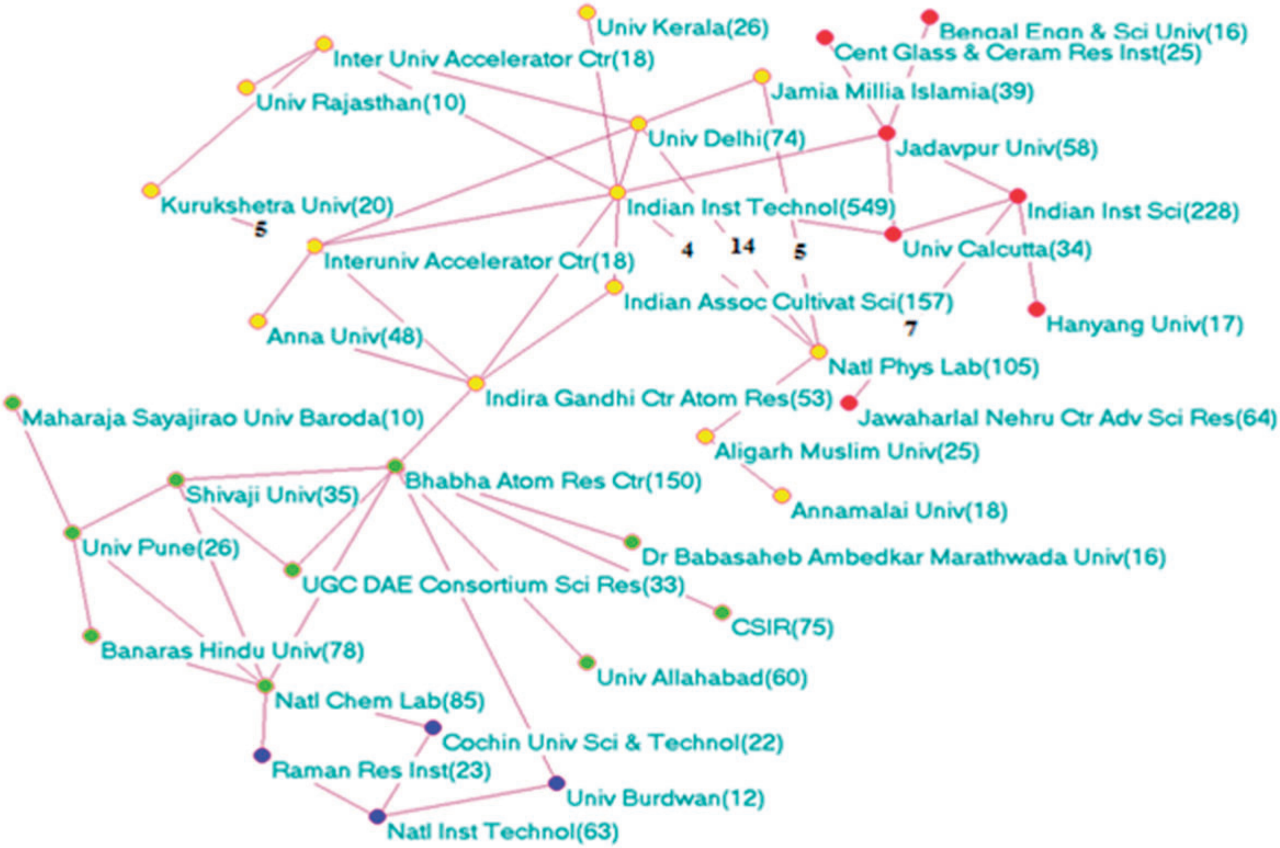


**Figure 3.** Linkages amongst active institutes, based upon co-authored publications in 2009. The different shades of the nodes indicate clusters where co-authorship was particularly strong.

Indian research institutes are also collaborating more. Whereas in 2000, 37% of the total papers involved at least two authors from different institutes (92 out of 247 papers published), nine years later 47% of the total number of papers were collaborative papers involving different institutes (1530 out of 3233 papers). We also observe a correlation between collaborative research and the quality of the paper, measured by the number of citations. Of the 26 papers in the top 1% cited papers in 2009, 17 papers (65% of papers) are the results of collaborations between different institutes, including seven with foreign organizations. Several initiatives have been taken to facilitate international collaboration in nanotechnology research. India has entered into a structural collaboration with nanotechnology researchers in Brazil and South Africa (IBSA-nano 2011) and connections with various European countries, the European Union and the USA are actively strengthened.

In general, institutional linkages developed from a sparse network (in 2001) towards a more connected network in 2009. Fig. 3 provides an overview of linkages among active institutes, based upon co-authored publications. As can be seen from Fig. 3, cluster formation has a bearing on geographical location. This formation may be due to the sharing of the sophisticated capital-intensive instruments required for nanotechnology research. Interestingly, a keyword frequency analysis showed that from 2000 to 2005 and 2009, sophisticated instrument like the atomic force microscope and the Fourier transform infrared spectroscopy are increasingly mentioned, indicating that those instruments are increasingly available to Indian researchers.

Industry has only a limited role in publishing, accounting for only 139 papers during the period 2000–9. The majority of the papers are collaborative papers involving industry and public research institutes. For example, of the 139 papers published by industry in 2009, 28 papers were collaborative papers. These small numbers indicate that the connections between public sector research and industry are still at the nascent stage. Nevertheless, several initiatives have been taken. Several state governments have, for instance, formulated plans for nanotechnology parks where public research institutes and companies can be located in close proximity to each other. Furthermore, both public and private actors have taken initiatives to connect research and industry. The national government has for instance erected the Center for Knowledge Management of Nanotechnology to provide information services on nanotechnology to researchers, industries, policy-makers and funders, industry-managed NGOs such as IndiaNano and the Nano Science and Technology Consortium have been created to provide platforms for bringing various stakeholders together. The TERI has also organized several workshops that brought a wide range of stakeholders together.

Indian patenting activity in nanotechnology is not particularly high. Consistent with earlier findings, we found that patenting activity in nanotechnology has increased sharply since the middle of the last decade (Mehta 2007; Agoramoorthy and Hsu 2010; National Foundation of Indian Engineers (NAFEN) 2008). Yet this activity is predominantly observed in applications filed. The number of patents granted is low. Until the early half of 2010, only 35 nanotechnology patents had been filed in the USPTO, of which only 15 have been granted. In the IPO, 1,356 patent applications in nanotechnology have been filed till the early half of 2010. By that time only 101 patents had been granted, of which 46 patents were granted to Indian institutions. Whereas Indian entities account for 289 applications, the great majority of these applications were filed by foreign entities. The USA for instance filed 562 applications, Germany 79, and Australia filed 67 patents in the IPO. Basic chemicals and pharmaceuticals were the main areas in which patents were granted, each accounting for 14 patents during the period 1998–2009. The main areas of focus within the technology classes were: nanopolymers, nanopharma and nanoelectronics. Academia is again dominating this activity; however, unlike the USPTO, firms are actively involved in the IPO.

There are some nanotechnology products on the market but an overview is hard to acquire. Some nano-enabled products are visible in textiles, sports, and cosmetics. Perhaps the best-known nanotechnology product in India is the Tata Swach. This water filter was launched in December 2009 and is being marketed as the 'water purifier for the masses' (SciDev.Net 2009). Nevertheless, our overall impression is that there are only a few products on the market. The Woodrow Wilson inventory of nanotechnology consumer products only finds two products from India (Project on Emerging Nanotechnologies 2011).

## 5. Discussions in India

### 5.1 Funding

The level of funding for nanotechnology is an issue of recurrent debate in India, across actors and forums. As was noted above, the most visible investments from the DST added up to 193 billion rupees in the period 2007–12. Yet despite a lack of clarity about the total investments made in India, funding has given rise to substantial discussion. Whereas some actors are satisfied with the amount of money available for nanotechnology R&D, others opine that not nearly enough is being invested. On the one hand, those satisfied with the level of funding applaud government investments and recognize that the levels of funding are relatively high in relation to other fields of research in India. On the other hand, critics draw attention to the low investments per capita (Niosi and Reid 2007), the limited set of funding initiatives, and the reluctance of India's industry to invest in nanotechnology R&D (Ramachandran 2006). Furthermore, critics have argued that in comparison to some foreign countries, India's investments are 'a drop in the ocean' (Varadarajan 2008). This discussion originated before the start of the Nano Mission but continued after this substantive funding initiative was started. Some discussion also focuses on the limited availability of venture capital. As one commentator noted, the:

> . . . Indian VC community is very small and stays far away from anything involving technology that is non-IT. (Srivastava 2008)

Allegedly, the few investors that can be found on the Indian market are only interested in finished products and in companies that have already passed the venture funding stage.

Connected to these diverging views about the level of funding are some concerns over the manner in which these investments are made, particularly over the lack of a clear development strategy. Although much has happened since the observation by Bhat that:

> . . . it is time India forges a nanotechnology policy in tune with the specific needs of the country and its existing strengths. (Bhat 2003: 154)

From time to time various actors have called for a strategy that is more transparent and detailed than current schemes. For instance NAFEN found that many scientists, when asked for measures to enhance nanotechnology activities, recommended that:

> . . . a clear government policy on various areas of use of nanotechnology relevant to India (e.g. application to energy sector, agricultural sector etc.) should be worked out. (NAFEN 2008: 36)

Reflecting the diverging views on the distribution of benefits, several Indian diaspora scientists have recommended that India focus on strategic areas rather than making generic investments in fundamental research (Ramani et al. 2011) and two influential Indian scientists have argued that:

> . . . it is important that India chooses the application areas for nanomaterials wherein either the Indian market is very large in the world context or which are unique/specific to India. (Sundararajan and Tata Narasinga Rao 2009: 37–8)

Similarly, The Energy and Resources Institute (2009b) recommends the formulation of a roadmap containing a more detailed and deliverable-bound objectives.

### 5.2 Capacity

Another issue of recurrent debate concerning nanotechnology in India concerns the capacity of India to be successful in nanotechnology. Again we see radically opposing positions. Particularly with reference to the capacity of the scientific workforce the various opinions expressed could hardly be more divergent. Numerous scientists note that India has an 'excess of talent' (*The Hindu* 2010) and therefore is 'poised to benefit' (Sen 2008) from nanotechnology, whereas simultaneously, others, such as the leading nanotechnology researcher in India, note that:

> . . . the real problem (. . .) is that we have to create the technical manpower to work in this emerging field. (C. N. R. Rao quoted in Ramachandran 2006)

The debate is often quickly narrowed to issues of education. Combining optimism with concern, scientists Agoramoorthy and Hsu (2010: 495) note that:

> . . . regardless of the economic prosperity supported by ample manpower, fulfilling India's nanotech dream will be a daunting task given the fact that educating, recruiting and supporting its next generation of scientists will be not only crucial but also absolutely necessary for India's future nanotech industry.

Similarly, researchers from the private sector have noted that an inadequate number of well-trained researchers is a major barrier for the development of nanotechnology in India (NAFEN 2008). The government takes a more cautious position by focusing its attention on educational matters, but is nevertheless drawn to the optimistic side of this discussion, frequently pointing out the potential of a large population and young workforce (Indo-Asian News Service 2007).

Also the capacity to properly regulate nanotechnology has been questioned, mainly by actors from NGOs. For instance the ETC Group (2010: 18) notes that:

> India's rollout of nanotech has been described as 'a free for all' due to the lack of regulation.

The TERI has also expressed its concern about the regulatory capacity to deal with several challenges nanotechnology poses to the existing regulatory landscape (The Energy and Resources Institute 2009a). Focusing on the capacity to deal with intellectual property rights, Barpujari (2010) notes that that currently, the IPO may not be well-equipped to handle nanotechnology. She argues that:

> . . . the case for building capacity of patent examiners and attorneys cannot be overemphasized. (Barpujari 2010: 211)

Similarly, while particularly expressing concern about the danger that granted claims will be overly broad, Jayakumar (2007) also observes that:

> . . . the Indian patent offices are not equipped with the individual and organizational structure, to deal with nanotechnology.

### 5.3 Commercialization and science–industry linkages

The commercialization of nanotechnology products and the linkages between science and industry are perhaps the issues that are most often addressed (Sundararajan and Tata Narasinga Rao 2009). Even the (then) President of India has repeatedly addressed the issue of connecting science with industry in the field of nanotechnology (Kalam 2006; Press Trust of India 2008). Although there are quite some companies involved in nanotechnology, as we discussed this in Section 4, it is often suggested that the amount of products is not in line with the large expectations or with the investments made. One scientist for instance observes that:

> . . . making the leap to commercial applications is complicated and is still a distant goal for most developing countries. (Raichur 2009)

Contrary to issues of capacity and funding, where discussions focus on the question of whether or not the supposed lack of capacity and funding is real, in the case of commercialization there seems to be unanimous agreement that commercialization is indeed a problem. More specifically, discussions about the commercialization often focus on the connections between science and industry, the argument being that:

> India's expanding nanotechnology research is not translating into market products due to weak links between Indian scientific institutes and industry. (Padma 2008)

One commentator notes that:

> Nanotech [in India] exemplifies the weakness of an improvised innovation system. (Bound 2007)

Both sides of the science–industry relation have been addressed. On the one hand, some commentators have attributed the gap between science and industry to companies, observing that:

> . . . unlike in the West, the industry here wants to enter at level 10; they want a ready-made product. (Singh 2010)

On the other hand, others have also pointed at scientists' affinity for fundamental research. Furthermore, as TERI (2009b: iii) notes:

> . . . the support provided by the government for nanoscience and nanotechnology has been characterised by emphasis on fundamental research.

Even though several measures to strengthen the linkages between science and industry have already been initiated, as mentioned in Section 4, a group of Indian nanotechnology scientists published an article calling on the government to create the infrastructure for collaboration in order to translate laboratory research into products (Press Trust of India 2010).

### 5.4 Regulation of risks

The regulation of risks to the environment, health and safety has been a matter of debate. More precisely, when potential risks of nanotechnology to health and the environment were addressed, it was aimed at making this a legitimate issue of concern. Whereas, in several other countries involved in nanotechnology R&D, issues of risk had become an area of attention, for a long time in India the focus remained almost exclusively on the benefits. As Srivastava and Chowdhury, two employees of TERI, put it:

> . . . the entire orientation of the current institutional and policy framework is towards strengthening technology development and its uptake by the industry. This has meant a significant neglect of the regulatory aspects relating to environmental, health, safety and ethical dimensions. (Srivastava and Chowdhury 2008a)

Nevertheless, in the second half of the last decade, the potential risks of nanotechnology increasingly became an issue of debate, partly due to the efforts by the TERI. In a series of reports, articles, and news items, they repeatedly addressed the potential risk of nanotechnology to the environment and human health as an issue worth discussing in the Indian context (The Energy and Resources Institute 2008, 2009a, 2010). A few years prior to that, a group of toxicologists at the Indian Institute of Toxicology Research had already began investigating the risks of nanotechnologies, partly through funding of the Department of Science and Technology and the European Framework Programs (Bhattacharya et al. 2012). By the end of the 2000s risks had been placed firmly on the agenda. Not only did scientists observe the need for regulating risks (Padma 2007; Raichur 2009), even Vice-President Hamid Ansari noted that:

> . . . we need to realise that new and revolutionary technologies always come as a package – with the promise of new opportunities and the threat of new risks. (AzoNano 2008)

And as has already been mentioned, in 2010 the government announced the establishment of a regulatory board for nanotechnology, even if thus far they have not been very transparent about their work. While industry is not particularly outspoken on this issue, it has been reported that at least half of industrial researchers identify the lack of safety measures as a major threat (NAFEN 2008).

Characteristic of the approach by the TERI—and in fact characteristic of discussions about the potential risks of nanotechnology in India at large—is that TERI does not take a strong adversarial stance. For instance in one of their reports, this NGO not only identifies gaps in existing regulations that could apply to nanotechnology but also thinks constructively and suggests ways to improve this situation, for instance by drawing up a multi-level governance framework for nanotechnology (The Energy and Resources Institute 2010). Similarly, although some newspapers still report that 'some of these dangers threaten the very existence of humankind' (Sharma 2007), in general the debate about the potential risks of nanotechnology in India is not polarized.

The discussion about potential risks almost exclusively focuses on regulatory aspects. Interestingly, whereas the TERI argues that:

> . . . in the present context, intervention at the level of subordinate legislation or amendments in the existing instruments, or interventions at the level of implementation can be made. (The Energy and Resources Institute 2009a: 5)

Several other actors that address the issue of risk regulation have called for entirely new regulation (Patra et al. 2009; Sharma 2010), even at the international level (Bürgi and Pradeep 2006). For industry, on the other hand, regulation is regarded as a potential obstacle to nanotechnology development. Seemingly particularly concerned about regulation slowing down technological developments, researchers from industry have called for faster approvals from regulatory authorities and the creation of a:

> . . . single window concept for regulatory mechanisms. (NAFEN 2008: 63).

### 5.5 Distribution of benefits

Finally there are discussions concerning the distribution of (potential) benefits of nanotechnology. Perhaps simplifying the matter somewhat, two positions can be discerned, each taken by a variety of actors, at times both are even taken by the same actor. On the one hand several actors focus their attention towards what nanotechnology can do for 'the masses of India' (AzoNano 2008). Scientists, government officials and NGOs alike have expressed the hope that nanotechnology enables the creation of products that can cater the needs of the poorest parts of the Indian population, with most attention going to the fields of energy, agriculture, and water (Bürgi and Pradeep 2006; AzoNano 2008; Sastry et al. 2010; The Energy and Resources Institute 2009b). A much cited example of such an application, particularly by foreign commentators, is a portable kit for the diagnosis of tuberculosis that was developed by India's Central Scientific Instruments Organisation. The kit is said to be quicker, cheaper, and use less blood than existing instruments for diagnosing tuberculosis and thus would be well-suited for rural areas with poor infrastructure (Meridian Institute 2005; Maclurcan 2005; Shetty 2010).

On the other hand a lot of attention is paid to the economic growth that nanotechnology may bring. Although many authors mention the possibility of pro-poor applications, the main focus lies with the enormous market potential that nanotechnology allegedly brings. Former President Dr. Abdul Kalam for instance noted that in the next decade nanotechnology will play a dominant role in the global business environment (Press Trust of India 2008) and the TERI has also written that:

> ... since nanoscience and technology is still emerging, it provides developing nations an opportunity to not only catch up with their developed counterparts but also offers the possibility to develop an advantage in core areas. (The Energy and Resources Institute 2009b: 3)

Again, scientists, government officials, NGOs and Indian diaspora scientists alike regard innovation in nanotechnology as a source of worldwide economic growth (Bhat 2005; Gereffi and Ong 2006; Kamath 2007; Agoramoorthy and Hsu 2010).

It should be noted that these two views on the distribution of potential benefits are not necessarily incompatible. For instance the tuberculosis diagnosis kit that is so often quoted in reference to its developmental benefits was, in fact, developed with its business potential in mind. As the chief developer of the kit mentioned:

> Once the prototype is ready, we will be among the few international players in the field. There is a huge billion dollar global market for such kits. (Times News Network 2004)

Similarly, the already mentioned nanotechnology-enabled water filter, developed by the industrial giant Tata Chemicals, is aimed to open up a new market amongst India's masses and will possibly be exported to Africa (SciDev.Net 2009).

## 6. Discussion

One of the most noteworthy features of the entrance of nanotechnology in India is the unanimously favorable opinion towards the technology itself. Our data shows that amongst those actors that have spoken out about nanotechnology, there is an overwhelming consensus on the desirability of investing in nanotechnology. Indeed, as we saw in Section 5, the issues that are raised predominantly focus on possible obstacles towards reaping the benefits of nanotechnology. The positive attitude towards nanotechnology also shows in the large expectations that accompany discussions about nanotechnology. Bürgi and Pradeep (2006) for instance write that nanotechnology will:

> ... for sure, revolutionize human society in an ever unprecedented manner. (Bürgi and Pradeep 2006: 645)

They also expect that:

> ... the possible impacts of nanotechnology will even go beyond those of the first Industrial Revolution. (Bürgi and Pradeep 2006: 648)

Such expectations are often constructed with reference to the global nanotechnology frontier. For instance C. N. R. Rao, often called India's 'nano-godfather', noted that:

> ... if we don't join the (nano) race, we will be left behind. (Srivastava and Chowdhury 2008a)

Taking this position one step further, another prominent Indian scientist notes that:

> ... in the coming years, India should aim for world leadership in at least some areas. Future Indian science should be based on daring and creativity, and it should try to be a leader, not a follower. (Mashelkar 2008: 307)

Besides reference to global leadership, expectations about nanotechnology are also framed in comparison to previous technologies. Srivastava and Chowdhury for instance note that:

> ... we missed the opportunity during the semi conductor revolution. We should not repeat that with nano technology. (Srivastava and Chowdhury 2008a: 6)

These unequivocally positive expectations provide a strong rationale for making investments in nanotechnology R&D, even though to a large extent discussions about nanotechnology remain technology-centered. Government officials, scientists, industrialists and civil society actors alike generally start observing the new properties enabled by nanotechnology, which are only then connected to a myriad of possible fields of applications. One could say that nanotechnology is a solution looking for a problem. Perhaps because of this, nanotechnology is never juxtaposed to other possible solutions to the problems that it is said to solve. One notable exception to this is M. S. Swaminathan, a well-known scientist who is widely regarded as the father of the Green Revolution in India. Starting from the perspective of insufficient agricultural production, Swaminathan doubts whether India should invest in nanotechnology rather than opting for technologies that are cheaper and already available, noting that:

> ... we should first disseminate ordinary technology to the farmer. (Sreelata 2008)

One issue that is notably absent from the list of challenges raised in India is the relation to the public. Whereas in many Western countries this is regarded as one of the most pertinent challenges in dealing with emerging technologies (Kjølberg and Wickson 2007), in India hardly any attention is paid to the role of the public in nanotechnology developments. A handful of authors have somewhat casually mentioned the need to improve communication to the public, noting that:

> ... consumer acceptance is the key when it comes to commercially-developed nanotechnology products. (Bürgi and Pradeep 2006)

But largely in the absence of studies on public opinion or media framing of nanotechnology to back up their concern,[4] and in the context of the virtually unanimous positive opinion about nanotechnology, such concerns have met with no response. Besides some small-scale initiatives to inform the public about nanotechnology by the science communication organization, Vigyan Prasar, no substantial initiatives can be witnessed. The same holds for the actual engagement of the public. Although TERI has occasionally drawn attention to public engagement and in 2008 the then Vice-President Hamid Ansari argued that:

> . . . all stakeholders, especially common people, must have a greater say in the development of nanotechnology. (AzoNano 2008)

These calls have thus far fallen on deaf ears.

Another issue that is equally absent in Indian discussions on nanotechnology is the ethical consequences of nanotechnology (Patra et al. 2009). This is remarkable when seen in the light of a recent study on scientists' and engineers' perception of ethical issues pertaining to nanotechnology. In their study, Patra et al. (2010) found nine different categories of ethical concerns being mentioned by scientists and engineers. When asked whether they knew of any ethical aspects of nanotechnology, Indian scientists mentioned items like: the use of nanotechnology in weaponry, animal testing, the blurring of boundaries between men and machine, and the self-replicating potential of nanoparticles. But despite a call by (again) Vice-President Ansari to prepare for dealing with the moral dilemmas that may follow from the disruptive outcomes of nanotechnology (AzoNano 2008), little is in fact done to actually address such ethical challenges. As Bürgi and Pradeep (2006: 652) neatly summarize:

> . . . little systematic research into the ethical consequences of nanotechnology has been undertaken so far.

## 7. Conclusion

This paper has sought to explore the developments, debates, and silences in India concerning science-based technologies that are characterized by novelty, high-growth, and potential broad impacts. Taking nanotechnology as a case, this paper combined a quantitative and qualitative approach to shed light on both developments in terms of governance and output as well as on the particular way in which India deals with challenges raised by emerging technologies. Such an assessment raises the corner of the curtain to provide a view on the situated nature of such developments, showing the particular way in which issues were (and were not) articulated and dealt with in India.

Nanotechnology in India is a government-led endeavor, with the government systematically investing in nanotechnology since 2001. Rather than focusing on the nation's strengths or needs, or on sectors or disciplines, investments in nanotechnology are made along the axes of fundamental or applied research, with the distribution of funds by the Nano Mission being divided into a science and a technology part. The priority of the government has been to create a strong institutional base, infrastructure support, and skilled manpower to develop nanoscience and technology, and some significant strides have been made toward achieving these objectives. Government investments have given rise to an increasing number of publications, institutions involved in nanotechnology R&D, collaborations in research, and the number of journals used for publication.

Of the issues that have emerged as challenges in India, we can see some measures being taken in the fields of funding, capacity, and science–industry linkages. These issues will require ongoing attention. For instance concerning science–industry linkages and product development, the growth in research output is mainly rooted in public research institutes and in fundamental research. While industry is starting to become involved and several products have appeared on the Indian market, developments in patenting and connections between science and industry are only at a nascent stage and developing slowly, giving rise to dissatisfaction by actors from science, industry, and civil society.

This is also related to one of the issues that is currently hardly addressed: the question concerning the distribution of benefits. Also here scientists, industrialists and civil society alike have expressed their dissatisfaction over the lack of a clear government strategy for nanotechnology. A useful first step would be the creation of a more detailed strategy that articulates the ways in which nanotechnology development should synchronize with the country's needs and objectives. Adding a strategic focus to the government's efforts will help in enhancing the capacities in industries where India intends to position itself in the world stage, for instance through creating focus for strategic science–industry collaborations. And the strategy will also increase the transparency that is required for opening up the debate about the framing of the technology—about what, where and how nanotechnology can contribute to the development and even the question whether nanotechnology is the right means with which to do so in the first place.

The Indian response towards nanotechnology has also differed in some ways from that in some Western countries. The relation between nanotechnology and the public—perceived as a pertinent challenge in many Western countries—is for instance hardly addressed in India, where opposition towards nanotechnology has not been visible. Also ethical issues pertaining to nanotechnology developments are hardly articulated as a noteworthy challenge. There seems to be an almost unanimously positive attitude towards nanotechnology that is expected to bring socio-economic progress across the board. Almost the entire institutional landscape is focused on promoting nanotechnology benefits. Both these differences and similarities between India and Western countries point to interesting avenues for future research on the situated response to emerging technologies.

In particular, the positive stance towards nanotechnology is somewhat surprising in the case of risks to human health and the environment. Potential risks of nanotechnology are an intense issue of debate, even if the desirability of nanotechnology itself is never questioned. After civil society organizations had initially put their back into it, more and more actors now identify risks as an issue of concern. Yet there is no nanotechnology-specific regulation and few checks and balances are in place. The government has only recently taken some initial steps towards dealing with such issues in a more proactive manner. It is hoped that more clarity about the activities of the anticipated nanotechnology regulatory board will be created soon in order to take away worries about the risks and to allow for a more transparent discussion of those risks. It is hoped that both government, scientists, industrial, and civil society actors will work together in creating a fruitful and responsible atmosphere in order to have nanotechnology contribute to Indian society.

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## Notes

1. Cleaning was done through expert consultation as simple lexical quarry led to many irrelevant records not related to nanotechnology.
2. Although Section 4 will include more quantitative information and Section 5 includes more qualitative information, the sections cannot be distinguished on the basis of the type of sources used. Both the discussion on developments includes results from qualitative study and the discussion on nanotechnology issues includes results from the quantitative analysis.
3. 50 Indian rupees are approximately one US dollar.
4. We only found one exception, a study on the framing of nanotechnology in Indian newspapers that was published as a working paper (Kanerva 2009).

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