On India's plunge into nanotechnology: what are good ways to catch-up?

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On India's plunge into Nanotechnology: What are good ways to catch-up?

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ABSTRACT

The present paper examines how a developing country like India is competing in the nanotechnology race. Our study shows that both upstream scientific and technological capabilities and downstream regulatory capabilities are being strengthened. India has clearly made a dent in terms of scientific publications (with the main focus being on nanomaterials), in the 'technology market' its patenting performance (with the principle focus on nanopolymers and nanocatalysts) though not extraordinary is good compared to other emerging economies spending similar amounts. In the 'final products' market some biotech and ICT incumbents are moving towards nano but the bulk of the new firms are in the field of nanomaterials. These achievements are particularly noteworthy given the much smaller quantity of funds invested by the Indian State as compared to the international leaders in nanotechnology. However, even with these initial optimistic results, the paper casts doubt on whether it is in the interests of economic growth or social welfare that India's science and innovation, and intellectual property policies are being increasingly modeled on the lines of developed countries so as to attempt to compete or collaborate with them without a better re-alignment and functioning of existing capabilities.

Key words: Catch-up, India, nanoscience, nanotechnology

JEL codes: O33, O38

On India's plunge into Nanotechnology: what are good ways to catch-up?

Following the 'ICT' (i.e. information and communications technology) and biotechnology revolutions, nanotechnology is the latest star in the set of 'radical' technologies' predicted to have the potential to profoundly change the mode of production in almost all industries. Defined as "the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications" [1,2] nanotechnology is expected to open up enormous vistas for experimentation and innovation generation (Drexler (1986), Harris (1999), The Royal Society (2004) and Foster (2006)). Like ICT and biotechnology, nanotechnology is a generic, platform technology with potential multisectorial applications. However, unlike ICT but more in line with biotechnology, nanotechnology promises applications that can promote inclusive development. For instance Salamanca-Buentello et al., (2005) spell out the types of nanotechnology applications, with specific examples, that can contribute to the attainment of each of the 'Millennium Development Goals' which 181 countries are committed to achieve during the coming decades. Given the world wide impact of ICT and biotechnology, and the announced glory of nanotechnology, it is no wonder that both developed and developing countries with established scientific capabilities are plunging to take part in the nanotechnology race – following the lead of the USA in terms of high public investment. However, the players have started the race at substantially different times. Furthermore, they do not have the same knowledge base, equipment or scientific and technological capabilities and the opportunity cost of every unit of funds diverted into this endeavour is higher for developing countries with a high poverty burden. In such a context, how should a developing country like India attempt to compete in the nanotechnology race? What are the trades-offs between the different trajectories for catching-up? These are the questions that we explore in this paper.

The case study of India is constructed using government documents, a survey of the economics literature and an examination of scientific publications and patents. This work can be considered as a contribution to the 'catch-up' literature of the evolutionary school of economics, which refers to a stream of rich and well documented historical case studies on the 'catching-up' processes of follower countries to build industrial capabilities. One of the factors repeatedly noted in these works as having been favourable to the catch-up process in knowledge intensive sectors, till the 1990s, is the international and sectoral diffusion of technology i.e a quasi-free access to international knowledge pools. The catching-up process of some of the now-developed countries and of Japan and thereafter East Asia in the post WWII period, has been largely explained in terms of efficient absorption and exploitation of existing superior technologies developed in the leading nations of their times, crucially supported by favourable public policy, State investment, and firm response (see Fagerberg and Godinho, 2003 for survey). Indeed, Fagerberg (1989) argues that catching-up process is essentially a dynamic process resulting from the confrontation of two conflicting forces: innovation in advanced countries that tends to increase the economic and technical gaps between backward and advanced countries; and diffusion and imitation of such innovation, which tends to reduce the gaps. Furthermore, Soete (1985) illustrates that when such international diffusion of knowledge occurs in combination with transition in technological

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[1] Definition according to the US National Nanotechnology initiative
http://www.nano.gov/html/facts/whatIsNano.html

[2] A nanometer is one-billionth of a meter

paradigms, it can sometimes open up 'windows of opportunity' which when exploited optimally can lead not only to 'catching-up' but even technological 'leap-frogging'. This occurs because follower countries may be able to leap to exploiting the latest and most efficient technologies and associated equipment, bypassing outdated intermediate technologies, which may be slowed down in leader countries by incumbent actors opposed to the integration of the new technology, given its potential for Schumpeterian style creative destruction.

In the past, effective exploitation of 'superior existing foreign technologies' by catching-up countries was possible with very loosely designed international intellectual property regimes (IPR). At the end of WWII, most countries followed the Paris Convention of 1883, the oldest international IPR convention of the time. The Paris Convention was quite open and gave freedom to the signatories to set up their own IPR systems, according to their nation's individual needs. This situation changed radically in 1995 with the creation of the WTO and the international homogenization of IPR regimes. The agreement on 'Trade-Related Aspects of Intellectual Property Rights (TRIPS)', signed by member countries of the WTO, calls for product patents in all sectors, thereby eliminating the possibilities for catching-up through re-engineering of original innovations.

Given that TRIPS makes the nanotechnology race (and all other technology races) operate under a 'winner takes all' rule – the chances of poor countries emerging as the big winners may seem quite dim. However, the bets are much more evenly dispersed across countries for nanotech than they were for example with biotech. As Niosi and Reid (2007; p.435) point out "It is interesting to note that while only 20% of the first 100 patents granted in the field of rDNA (biotech) were to foreign patent applications, 45% of the nanostructure – related granted patents were granted outside of the USA (USPTO database). Additionally, while the rDNA patents were not dispersed widely across many countries (i.e., mainly only in the USA, Japan, and a few European countries), the nanostructure patents were widely dispersed across more countries including Korea, Singapore, and China."

Then, what are the strategies possible for developing country firms and laboratories to carve out a niche for themselves in the nanotech markets? According to the catch-up literature acquisition of scientific capabilities is the first the necessary step to build final market capabilities in a new knowledge intensive sector – but this may not be enough. For example, financial-institution capabilities to bear the costs of risky investment (Gershenkron, 1962), an educated work force with social capabilities (Abramovitz, 1986), and public labs and firms with technological capabilities (Lall, 1992) may be crucial. Soete and Perez (1988) also point out that entry into a 'catch-up trajectory' and the 'target sector' and 'the target phase of the life cycle of the technology' (i.e. take-off, high growth stage, emergence of a dominant paradigm and maturity) to enter would depend on the follower-country's resource and capabilities base given the fixed cost of investment demanded for entry, scientific base in terms of qualified personnel, location advantages and anterior skills and experience required.

With respect to India, Bhat (2005), of the Department of Scientific and Industrial Research of India, suggests that India is impeded by the lack of sufficient government funding to research upstream and a lack of adequate private financing in the form of seed funding, angel funding or venture capital downstream, from making a dent in the nanotechnology markets. In a more detailed prospective study of India supported by figures, Niosi and Reid (2007) echo the same argument. They point out that India has both scientific and social capabilities in terms of having large populations of engineers, doctors and universities, departments of public institutions doing research in nanotechnology, English as the language of work, and some technological capabilities that could be used to enter nanotechnology via established software companies and new firms dedicated to nanotechnology. They see the bottleneck as for most developing countries to be the 'financial one' – if India can mobilize the financial resources in sufficient quantities to build first rate scientific labs and if private financiers can support entrepreneurs and their new ventures, windows of opportunity might be seized.

Patra et al. (2010) temper the above picture with a detailed analysis of the perceptions of 58 practitioners of nanoscience and/or nanotechnology in India. They could find only one practitioner from industry – indicating that *nanoscience and/or nanotechnology* (or NST from now on), has yet to be widely incorporated in the R&D programs of Indian firms. Of those interviewed, 60% feel that there are unresolved 'ethical' issues that need to be addressed more. They are of three main types. First, public and private investment in India is being taken on the basis of premises and promises unsupported by rigorous technology and product forecasts, and this may lead to bubbles that burst without yielding dividends. Second, entrenched participation with higher investment may increase inequalities between rich and poor countries (because of the capital investment required for experimentation and innovation) and between the rich and the poor within a country (because of the product focus of applications). Third, while developing capabilities in experimentation and production of nanomaterials may yield monetary payoffs through local production and contracts from abroad, they also present the maximum risk for the environment, subjects of experiments (say animals) and the workers involved in experiments and production[3].

A panel of world renowned scientists and economists from developed and emerging countries, point out that government policy in both developed and developing countries resemble "an embrace of imagination rather than a systematic use of what Sun Tzu and others have taught us about strategic decision making" (Roming Jr. et al., 2007). They confirm that NST has the potential to generate useful applications in energy production and storage (especially in solar energy), providing potable drinking water, improving agricultural production, storing agricultural products and meeting medical and healthcare needs. At the same time they call for a comprehensive survey of the threats posed by NST for societal welfare and education of all from policy makers to school children, as informed and well thought out strategies cannot be identified otherwise.

In the light of the above, it is clear that in order to understand and evaluate the impact of India's engagement in NST it is necessary to delve into details about the Indian system of innovation and the strategies of the stakeholders involved. By 'national systems of innovation or (NSI)' with respect to NST, we refer to all actors (State, firms and institutions) involved within a country on nanoscience and/or nanotechnology. The NSI approach spearheaded by the seminal work of Lundvall (1992), Nelson (1993), Freeman (1995) and Edquist (1997) has emerged as a useful framework to study the building of different capabilities by countries and regions.

The rest of the paper is organized as follows. Section 2 introduces the main actors in the Indian system of innovation with respect to nanotechnology and briefly presents the main features of public investment in nanotechnology. Section 3 examines the existing institutional landscape of regulatory agencies that will play a critical role in the commercialization of

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[3] Currently, asbestos is banned in all developed countries because its particles contribute to a cancer all mesothelioma; however, it is widely used in developing countries (including the poor), especially by the poor, as asbestos sheets are hardier than plastic or thatched roofs and equally cheap. The length of nanparticles are in the same range as asbestos particles and toxic nanomaterials such as tellurium, selenium, arsenic etc. cannot be handled easily (Patra et al.).

nanotechnology based products and processes. Section 4 examines the publications and patents output. Section 5 evaluates the Indian trajectory in nanotechnology, identifies the challenges for the Indian system of innovation to carve out a meaningful niche in nanotechnology and concludes with policy recommendations.

2. Indian NST system of innovation

2.1 Introducing the actors in NST

The most important actor in the nanotechnology landscape is the Indian government. Enthused by the potential economic benefits of nanotechnology the Government of India (GOI) initiated the first national program, termed the 'Nanoscience and Technology Initiative (NSTI)' in 2001. It was implemented by the Department of Science and Technology or DST and between 2001-2006 about 600 million Rupees (or Rs 60 crores) was invested in about a 100 basic research projects on nanoparticles, nanomaterials (e.g. nanotubes and nanowires) and nanodevices (e.g. DNA chips) and in establishing centres for nanoscience. The objective was not only to develop scientific capabilities but also to develop new products[4].

On the basis of the first results obtained, in 2007 the Government upscaled its investment and launched a dedicated program – the 'Nano Mission' (or NM) which according to its website is an: "umbrella programme for the capacity building which envisages the overall development of this field of research in the country and to tap some of its applied potential for nation's development". The steering body for the NM is the Nano Mission Council, which in turn is assisted by two advisory bodies – the Nano Science Advisory Group (NSAG) and the Nano Applications and Technology Advisory Group (NATAG). Membership of these bodies is mainly drawn from the DST, science research institutes and private companies involved in nanosciences and technology. The mandate given to the NM is primarily one of technology development through the targeted funding of basic research facilities and human resources, by creating strategic partnerships between industry and research institutes.

The primary difference between the two successive programs is that: (i) the NM has a significantly larger budget (approx USD 230 million); and (ii) organizationally, its members include not only research scientists from public research institutes but also from industry, as well as other representatives of government departments and industry. The NM is a novel initiative of the GOI, in the sense that it intends to provide a '*focussed strategy*' of public research investment that will *drive* innovation, dissemination and further development of nanotechnology in India (TERI, 2010). Within the Central Government there are also several departments that have undertaken nanotechnology research programs in their respective niches as indicated in table 1.

Table 1: Major State Departments involved in nanotechnology

Department	Thrust area
Department of Biotechnology - DBT	Nano-bio
Defence Research and Development	fullerenes & Nano tubes; diagnostic tools for

[4] Presentation of Dr. Vivek Srivastava at the "Workshop on nanotechnology: Current status and Challenges" - Indian Institute of Technology, Delhi, July 20, 2007 - http://www.nanotech-now.com/columns/?article=083

Organization - DRDO	tuberculoses and typhoid
Ministry of Communication and Information Technology - MCIT	Nanoelectronics
Department of Atomic Energy - DAE	NST in general
Department of Scientific and Industrial Research –DSIR under DST	NST in general

Below the Central Government are the set of State Governments some of which are also interested in developing NST capabilities. Notable among them are the state governments of Karnataka, Andhra Pradesh and Tamil Nadu, which have been very active in promoting their respective states as favoured destinations for investment in nanotechnology-based industries. All these three states have benefited economically from the IT revolution that swept India over the last few decades. Nanotechnology is being seen as potentially an even bigger success story than ICT and therefore the optimism of these states is unsurprising. In the case of Karnataka and Andhra Pradesh, the government has promised to set up dedicated industrial parks for nanotechnology-based industries. The Tamil Nadu government has even supported nanotechnology conferences in the state, through the Technology Developed and Promotion Centre (TDPC) that was set up as a joint initiative with the CII (Confederation of Indian Industry).

Besides the public actors, the most important type of private actors engaged in the promotion of NST in India are the industry associations such as the Associated Chambers of Commerce and Industry in India (ASSOCHAM), the Federation of Indian Chambers of Commerce and Industry (FICCI) and the Confederation of Indian Industry (CII). Industry associations are focussed on promoting nanotechnology in various industrial applications. The Confederation of Indian Industries (CII) launched its nanotechnology initiative in 2002 and has a ten-point action plan for streamlining the development and commercialization of nanotechnology products. Other industry associations and business promotion organizations, such as the Associated Chambers of Commerce and Industry of India (ASSOCHAM), are also looking at pharmaceuticals, FMCG (fast moving consumer goods) and electronics as key areas for nanotechnology applications. These associations have been promoting nanotechnology not only at the national level but also at regional levels as well. In Tamil Nadu, a joint programme between Tamil Nadu Technology Development & Promotion Centre (TNTDPC) and CII is building awareness. The Tamil Nadu government is proposing a nanotechnology park, along the lines of the Hsinchu Science Park in Taiwan. In the state of Kerala, a new centre has been established as the first initiative funded by the Government of India for nanotechnology in tissue engineering and stem cell research.

2.2 Building of scientific capabilities

Public investment is being mobilized to create scientific capabilities through four types of strategies: creation of new research units, promotion of basic research, investment in human resource development and public-private partnerships.

Setting up of new research units in established centres of excellence: Under the NM program, a chain of Centres of Excellence across the country have been established, in three forms. First, are Nano Science operating units within the established science departments of the various IITs (Indian Institutes of Technologies), the Indian Institute of Science (IISc) in Bangalore and other central universities, such as the Benares Hindu University (BHU) and University of Pune. Second, a fully fledged Centre for Nanotechnology within specialized science institutes like the Tata Institute of Fundamental Research (TIFR); with specific research focus, ranging from Nanodevices, Nanocomposites, Nanobiosensors at the Indian Institute of Science (IISc) to focus on Photovoltaics and sensor devices at the Indian Associate for Cultivation of Science in Kolkata. Third, is the Centre for Computational Materials Science at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) that was set up in Bangalore.

Financing of specific research projects: For the moment the focus is on toxicology and the research has been undertaken primarily by the IITR (Indian Institute of Toxicology Research), the Indian Institute of Chemical Technology (IICT) and the NIPER (National Institute of Pharmaceutical Education and Research). Both the IITR and the IICT are R&D institutes that are overseen by the CSIR while the NIPER operates as an autonomous body under the Department of Pharmaceuticals of the Ministry of Chemicals and Fertilizers.

Another key area is the biomedical research and this operates mainly under the aegis of the ‘Indian Council of Medical Research (ICMR);. The ICMR is the lead body (functioning under the Ministry of Health and Family Welfare) and it has funded studies on the toxicity of polymeric nanoparticles , the use of nanoparticles in cataract operations and also run conferences on nano-biotechnology applications. The ICMR has therefore been active in funding research on both applications and toxicology challenges with specific reference to nanomedicines.

Building human resource capabilities: Another important aspect of NM is human resource development. Under this initiative, seed funding has been provided to universities for developing postgraduate level (M.Sc. and M.Tech.) teaching programs on nanotechnology. The purpose here is to provide students and researchers coming from different fields exposure to and training in NST so that interdisciplinary research can be facilitated both in public laboratories and private firms.

Initiating public-private partnerships: Several have been launched with the leading scientific institutions and sets of private firms targeting specific results. For instance under the ‘Nano mission’ a notable partnership is the research program on ‘Smart and Innovative Textiles (SMITA)’ at the IIT in Delhi. Private participants include Pluss Polymer Pvt. Ltd., Purolater India Ltd. and Resil Chemicals. The program focuses on new generation methods for novel materials such as nanofibres, nanofinishes and encapsulated phase change materials, and also on experimenting with new methods for encapsulating such materials into the textile substratum.

2.3 Gearing up the Regulatory Framework: institutional mandates and issues of synergy

Four vital policy areas that are critical to the success of nanotechnology in India are metrology, the patenting regimes and regulations on technology transfer and risk regulation . The actors in these areas are presented below in box 1 and also illustrated in figure 1. These organizations have been identified on the basis of their current activities in the field of nanotechnology as well as their policy mandates that will impact nanotechnology developments in India more generally.

Architecture of Regulatory Institutions

1. **MST (Ministry of Science and Technology) & the institutions operating under the purview of MST**
    a. DST (Department of Science and Technology)
    b. DSIR (Department of Scientific and Industrial Research)
        i. NRDC (Public Sector Enterprise)
        ii. TIFAC (Technology Information, Forecasting and Assessment Council)- AUTONOMOUS BODY
        iii. CSIR (Council of Scientific and Industrial Research) – AUTONOMOUS BODY
            1. NPL(National Physical Laboratory)
            2. NCL (National Chemical Laboratory)
            3. IICT (Indian Institute of Chemical Technology)
            4. IITR (Indian Institute of Toxicology Research)
    c. DBT (Department of Biotechnology)
    d. Department of Atomic Energy (DAE)

2. **MOHFW (Ministry of Health and Family Welfare) & institutions under its purview**
    a. ICMR (Indian Council of Medical Research)

3. **MCIT (Ministry of Information Communication and Technology)**

4. **MCF (Ministry of Chemicals and Fertilizers) & institutions under its purview**
    a. NIPER (National Institute of Pharmaceutical Education and Research) – AUTONOMOUS BODY

5. **DAE (Department of Atomic Energy)**

6. **DRDO(Defence Research and Development Organization)**

7. **Bureau of Indian Standards (BIS)**

8. **MoCI (Ministry of Commerce and Industry)**
    a. DIPP (Department of Industrial Policy and Promotion)
        i. Controller General of Patents, Trademarks and Designs

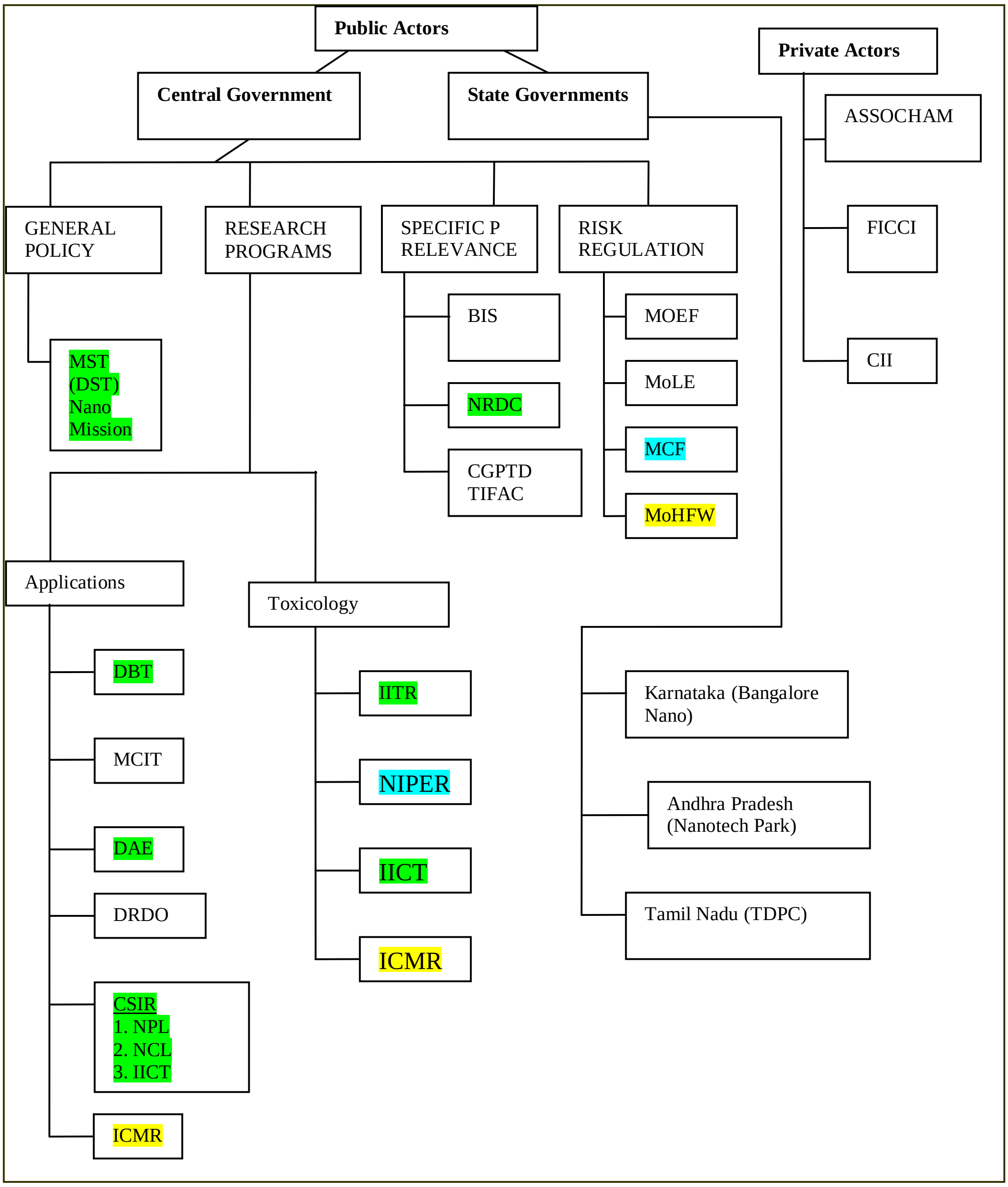
9. **MOEF (Ministry of Environment and Forests)**

10. **MoLE (Ministry of Labour and Employment)**

11. **TDPC (Technology Development and Promotion Centre)**

12. **ASSOCHAM (The Associated Chambers of Commerce and Industry in India)**
13. **FICCI (Federation of Indian Chambers of Commerce and Industry)**
14. **CII (Confederation of Indian Industry)**

Figure 1: Key Institutional Actors in Nanotechnology Policy in India



2.3.1 Metrology and Standard Setting

The Bureau of Indian Standards (BIS) is the national standards authority and is an autonomous body under the purview of the Ministry of Consumer Affairs, Food and Public Distribution (MCA). Its main functions are standards formulation and the certification of products and systems. In early 2007 and then in late 2009, BIS set up two sectional committees: one on nanotechnologies (MTD 33) and the other on medical biotechnology and nanotechnology (MHD21). While the former liaises with the corresponding international committees (ISO/TC229/WG2) on measurement and characterization, the latter participates in the ISO/TC229/ WG 3 on the health, safety and environmental aspects of nanotechnologies.

Nano devices, sensors, transistors, initiators and atomic force microscopy have all been identified as priority areas by MTD 33. However, consumer products are currently not in the agenda. Given its participation in the ISO technical committee on nanotechnology, the BIS is the principal actor working on standardization aspects that will form the foundation for the risk assessment of nanomaterials.

The BIS is linked to other institutional actors which either finance research or undertake research in NST such as the DST, DIT, and various CSIR laboratories; including the NPL which participate as members of MTD 33. The ICMR is one of the participating members of MHD21.

2.3.2. Gearing up the patent bureaucracy on paper and in practise

Nanotechnology is an enabling technology, and therefore, several new products across sectors such as agriculture, textiles, pharmaceuticals and electronics are expected to be introduced in the market in the coming years. Patents published in this field suggest that nanotechnology represents the convergence of several 'classical fields of science' such as – physics, chemistry, biology, medicine and pharmacology. Therefore, developing intellectual property in this field, represents a challenge both for the scientist or researcher doing basic research and developing technology applications, as well as patent authorities who need to vet such applications. A favourable environment for the protection intellectual property rights is a critical pre-requisite to product innovation.

. As of now there have no changes to deal with NST related applications in the existing patent regime. In practise, the situation is even more complex. In the past, when reengineering was permitted, the Indian Patent Office (IPO) was rather sparsely staffed and equipped as guarding technology as 'trade secrets' was as good or even a better protection against second innovators than a patent application. With the signature of TRIPS in 1995 and the ensuing amendments to the Indian patents regime, the IPO began increasing its staff. However, as Barpujari (2010) points out, there is a human resource crisis in terms of patent attorneys who are well knowledgeable in both law and new technologies like NST or biotechnology. The digital databases of the IPO are difficult to use. This is a problem not only with India but all developing countries which have had to adopt TRIPS.

The Indian patent office is further assisted by facilitation centres such as the Technology Information, Forecasting and Assessment Council (TIFAC), which is an autonomous institution within the DST, well positioned to link up with the current nanotechnology research programs that are being funded by the various government departments.

2.3.3 Facilitating Technology Transfer

Besides technology transfer effectuated under the Nano mission, technology transfer is promoted by the National Research Development Corporation (NRDC) which operates as a public sector enterprise, under the control of the DSIR, providing technical assistance (including specification drafting in patent applications), licensing agreements and consultancy services to technology developers. One of the major technologies that it has licensed is an improved formulation (nimesulide based) for ocular delivery using nanotechnology.

2.3.4. Risk Regulation

Given their small size and unique properties, nanomaterials are valuable in a wide variety of sectors. However, those same features may make some of the nanoscale materials active in the environment and therefore potentially hazardous for both human health and environmental safety. The challenge of regulating nanomaterials is especially great, given their diverse nature (e.g. sizes, particles, functionalities) and, since it is a platform technology, the range of applications is virtually limitless. Even so, at present there are a variety of regulations in India that are also applicable to nanomaterials to ensure:

- occupational health and safety (both at the research laboratory and in manufacturing)
- environmental safety (life cycle analysis(LCA), emissions and waste)
- product and consumer safety (LCA, food chain, waste and emissions)
- guidelines for the sustainable use and safe handling of nanomaterials.

Moreover, the above identified regulatory matters are the concern of the following ministries:

- Ministry of Environment and Forests (MOEF)
- Ministry of Labour and Employment (MoLE)
- Ministry of Health and Family Welfare (MoHFW)
- Ministry of Chemicals and Fertilizers (MCF).

The regulatory mandate of the above Ministries is summarized in table 2. As can be seen there are a variety of laws that could impinge on the commercialization of nanomaterials. All have been conceived to ensure safety to humans and the environment.

Furthermore, two of the regulatory agencies also have a mandate to promote research and oversee the functioning of research organizations. The Ministry of Health and Family Welfare (MoHFW) supports toxicological studies relating to nanoparticles in health applications through the Indian council of medical research (ICMR). And the Ministry of Chemicals and Fertilizers (MCF) via the Department of Pharmaceuticals (DP) finances projects on the toxicology aspects of nanomaterials in NIPER. Their dual functions in terms of regulatory mandates and also scientific expertise of course leads to some overlap.

Table 2: Regulatory Mandate of Government Agencies

Nodal Agency	Implementing agency	Focus	Associated Laws
Ministry of Environment and Forests (MOEF)	Central Pollution Control Board (CPCB) The State Pollution Control Boards (SPCBs)	Environmental protection, pollution prevention and pollution abatement	- Environmental (Protection) Act of 1986 (EPA), - Air (Prevention and Control of Pollution) Act 1987, - Water (Prevention and Control of Pollution) Act 1974 - The Public Liability Insurance Act of 1991 - Hazardous Material (Management, Handling and Transboundary Movement) Rules 2007; - The Bio-Medical Waste (Management and Handling) Rules, 1998; - The Municipal Solid Wastes (Management and Handling) Rules, 2000
Ministry of Health and Family Welfare (MoHFW)	Central Drugs Standards Control Organization (CDSCO) State Drug Controllers	Regulation of health applications that use nanomaterials or nano particles such as carbon nanotubes for targeted drug delivery ; nano gold particles for use in diagnostic devices	- Drugs and Cosmetics Act, 1940(DCA)
Ministry of Labour and Employment (MoLE)	??	Occupational health and protection from hazards in workplace	The Factories Act, 1948
Ministry of Chemicals and Fertilizers (MCF).	-The Department of Chemicals and Petrochemicals (DCP), -The Department of Pharmaceuticals (DP).	Regulation of all drugs and pharmaceuticals not allocated to MOHFW?	- Drugs and Cosmetics Act, 1940(DCA)??

***Compiled by the authors*

3. Achievements: publications, patents, products & new firms

3.1 Scientific publications

The corpus of scientific publications was constructed using the database 'ISI Web of Knowledge' supplied by Thomson Reuters, and in particular the section 'Web of Science' (WOS) and within this the 'SCI Expanded' or Science Citation Index Expanded. This is an international reference in bibliometrics covering over 8500 journals in various disciplines indexed by their impact factors, and offering access to a variety of tools for 'search' by author, type of document, language, country, organization, year of publication, source and theme. Within the WOS, the JCR or the 'Journal Citations Report' is an instrument that analyses SCI Expanded. For instance JCR considers 158 scientific domains and to each journal it attributes one or more of these scientific domains. Thus, we first identified 46 journals as being affiliated to the category "Nanoscience & Nanotechnology" by the JCR. Then we extracted records of publications between 1978-2008 in these 46 journals by formulating our research equation as the union of the titles of the 46 journals and applying it to the field 'SO' or journal source[5] of WOS. By delineating our corpus in this fashion, like Loet Leydesdorff (2008), we opted to accommodate the possibility of having 'excess silence' rather than 'excess noise'.

In our database out of the 66353 publications from the 46 journals between 1978-2008, 2447 publications (i.e. 3.68%) had at least one author with at least one address in India and these 2447 articles formed our corpus for carrying out a detailed bibliometric analysis. We identified the trends in publications over time, the penetration of journals, the leading authors, the leading institutions and nature of collaboration. Finally, we carried out some basic statistical tests on the 'abstracts' of the 2447 publications using the program Alceste to identify the focal points of Indian publications and the weights of each focal point. Here, we

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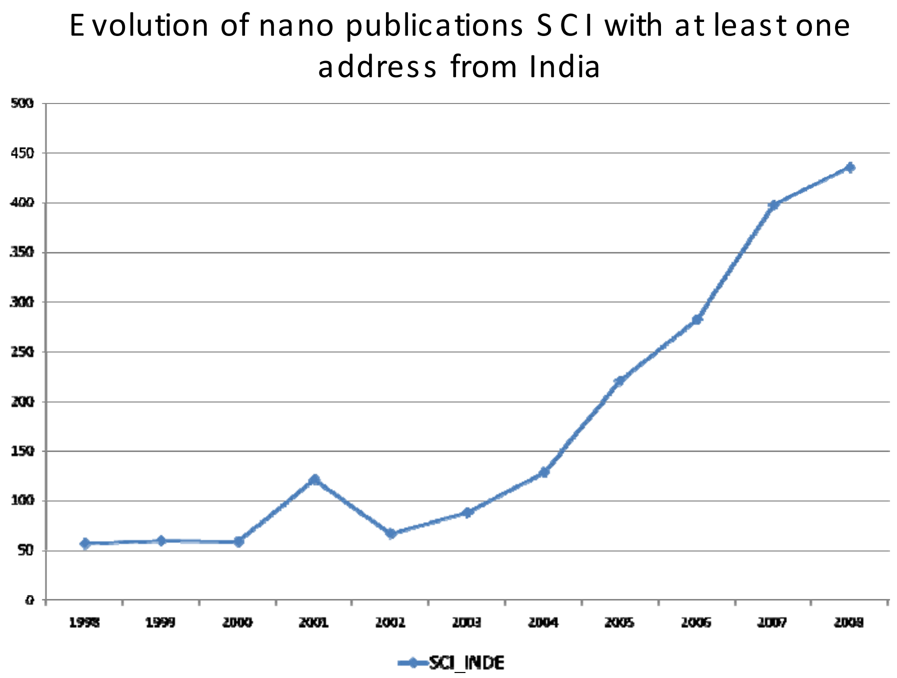
[5] *SO="ACS Nano" OR SO="BIOMEDICAL MICRODEVICES" OR SO="Biomicrofluidics" OR SO="BIOSENSORS & BIOELECTRONICS" OR SO="Current Nanoscience" OR SO="FULLERENES NANOTUBES AND CARBON NANOSTRUCTURES" OR SO="IEE Proceedings-Nanobiotechnology" OR SO="IEEE TRANSACTIONS ON NANOBIOSCIENCE" OR SO="IEEE TRANSACTIONS ON NANOTECHNOLOGY" OR SO="IET Nanobiotechnology" OR SO="International Journal of Nanomedicine" OR SO="International Journal of Nanotechnology" OR SO="Journal of Computational and Theoretical Nanoscience" OR SO="Journal of Experimental Nanoscience" OR SO="JOURNAL OF MICROLITHOGRAPHY MICROFABRICATION AND MICROSYSTEMS" OR SO="JOURNAL OF MICROMECHANICS AND MICROENGINEERING" OR SO="Journal of Micro-Nanolithography MEMS and MOEMS" OR SO="Journal of Nanoelectronics and Optoelectronics" OR SO="JOURNAL OF NANOPARTICLE RESEARCH" OR SO="JOURNAL OF NANOSCIENCE AND NANOTECHNOLOGY" OR SO="JOURNAL OF VACUUM SCIENCE & TECHNOLOGY B" OR SO="LAB ON A CHIP" OR SO="MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROST" OR SO="MICRO" OR SO="Micro & Nano Letters" OR SO="MICROELECTRONIC ENGINEERING" OR SO="MICROELECTRONICS JOURNAL" OR SO="MICROELECTRONICS RELIABILITY" OR SO="Microfluidics and Nanofluidics" OR SO="MICROPOROUS AND MESOPOROUS MATERIALS" OR SO="MICROSCALE THERMOPHYSICAL ENGINEERING" OR SO="MICROSYSTEM TECHNOLOGIES-MICRO-AND NANOSYSTEMS-INFORMATION STORAGE AND PROC" OR SO="NANO LETTERS" OR SO="Nano Today" OR SO="Nanoscale and Microscale Thermophysical Engineering" OR SO="Nanoscale Research Letters" OR SO="NANOTECHNOLOGY" OR SO="Nature Nanotechnology" OR SO="Photonics and Nanostructures-Fundamentals and Applications" OR SO="PHYSICA E-LOW-DIMENSIONAL SYSTEMS & NANOSTRUCTURES" OR SO="Plasmonics" OR SO="PRECISION ENGINEERING-JOURNAL OF THE INTERNATIONAL SOCIETIES FOR PRECISION" OR SO="REVIEWS ON ADVANCED MATERIALS SCIENCE" OR SO="SCRIPTA MATERIALIA" OR SO="Small" OR SO="Synthesis and Reactivity in Inorganic Metal-Organic and Nano-Metal Chemistr"*

summarize our results only – the data pertaining to the following results are presented in the appendix.



Publications issuing from India related to NST can be characterized as follows:

- **Steadily growing since 2002**: Indian publications are steadily growing; India is doing well in BRICS group of countries but is considerably behind China, which however is spending far more on building scientific capabilities. (see figures A1 and A2 in appendix).
- **Large penetration of international journals**: Out of the 45 journals corresponding to the subject category "Nanoscience & Nanotechnology" of JCR, Indian authors have published in 36 journals. (see table A1 in appendix)
- **Mostly co-authored papers**: Out of the 2447 articles, only 88 or 3.6% had only one author (with address from India) and 2359 were co-authored.
- **Top publishing authors do not only come from the institutions which received the maximum of funds for nanotechnology**: This shows that there is scope for institutional improvements and synergy generation. (see table A3 appendix)
- **There is one central institutional actor which is at the heart of collaborations namely the IIT[6]:** Figures A3 and A4 of the appendix indicate the networks between institutions which have more than 4 collaborations. As can be seen the 'IIT' is the

[6] IIT = Indian Institute of Technology – a network spread over India; IISc = Indian Institute of Science – based in Bangalore.

most central actor or collaborating with a maximum variety of institutions – this is followed by the 'IISc'. There are also three smaller networks that seem to have developed due to geographical proximity or individual initiative.

- **Very little international cooperation and mostly with high-income countries:** Out of the 2447 publications with at least one author from India, 1914 or 78.22% of articles were written exclusively by Indians between themselves (with one or more authors with only Indian addresses). In the corpus, 533 articles are written in collaboration with researchers in foreign countries and out of these, 501 articles arewith researchers in high-income countries[7]

- **The top five countries of collaboration are the NST leaders:** The top five collaborating countries are USA, Japan, Germany, South Korea and France (see table A4 in appendix).

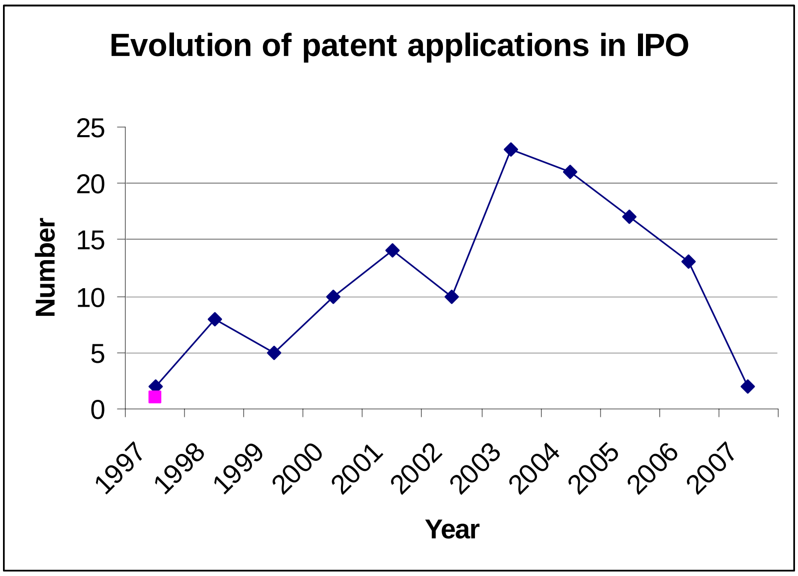
- **In terms of importance nanomaterials tops the list:** Out of the 1914 articles written exclusively by Indians, 880 articles (or nearly 46%) of the publications are in journals that deal only with nanomaterials.

- **In terms of variety there are three main points of focus:** Applying the standard method of cluster analysis on the abstracts of articles, we obtained three main clusters – which were indicative of a publications focus on three main areas in decreasing order of importance: (i) behaviour of nano-materials especially in different kinds of alloys; (ii) Nanoparticles and nanomicroscopy in relation to nano-optics and (iii) nanobio. (see figure A5 in appendix)

3.2 Patents

The knowledge base of any organization or region in terms of patents depends on the 'search strategy' as well as the 'database used'. Often the results are very different as a function of the above. For instance, the use of the lexical query 'nano*" on the 'Indian Patent Information Retrieval System' yielded 124 records of granted patents. Of the grantees 61 are Indian entities. The CSIR holds the maximum number of patents, followed by the IITs. The three Indian firms present are all pharmaceutical firms: Ranbaxy, Dabur and Lifecare innovations. The first patent applications containing the word 'nano' has appeared in 1997. The average time of granting of patent seems to vary between 2 to 4 years, though there are a few patents which have taken 5-10 years to be granted. The evolution of granted patents is given in the figure below.

[7] High income countries as defined by the World Bank.



We then examined patents in the European Patent Office base (or EPO) and the US Patent Office records (or USPTO). In the EPO, the class 'Y01N' is the tag applied to nanotechnology while in the USPTO', '977' is a class signifying affiliation to nanotechnology. We applied the search strategy by which we extracted patents with the EPO-ECLA affiliation 'Y01N' and USPTO affiliation – and with 'India' as 'priority country' i.e. country where it was first applied for. This yielded the results given below.

Code	Title	EPO WO	USPTO
Y01N0002	**Nanobiotechnology**	**13**	**5**
Y01N0004	Nanotechnology for information processing, storage and transmission **Nanoelectronics**	4	3
Y01N0006	Nanotechnology for materials and surface science **Nanomaterials**	16	10
Y01N0008	Nanotechnology for interacting, sensing or actuating **Nanodevices**	0	0
Y01N0010	**Nanooptics**	**0**	**0**
Y01N12	**Nanomagnetics**	**2**	**2**

Again in both these data bases, CSIR holds the maximum number of patents. The Indian firms CIPLA and Panacea hold EPO patents and Torrent Pharmaceuticals is an USPTO patentee. It is interesting that even within the IPO, EPO and USPTO – the Indian firms which are present are different and the images of focal points are so different (refer to table above).

Finally, following trends in the academic scientometric literature we used a number of standard lexical queries (see Huang, Notten and Rasters, 2010 for survey) to evaluate the 'scope of the Indian presence' in EPO and USPTO. Instead of going by the classification of the patent examiners – these lexical queries look for 'words' that are present in the patent texts itself. Each string of words corresponds to a lexical query. The longer the string, the greater the risk of 'noise' i.e. inclusion of patents irrelevant to nanotechnology; while the shorter the string of words the greater the risk of 'silence' or exclusion of patents pertinent to nanotechnology. We used the queries as developed by Glanzel et al. (2003), Muller (2006), Porter et al. (2008) and Mogoutov and Kahane (2007) and we crossed them on patent applications with 'India' as the country of 'priority'. The images obtained of the Indian presence varied starkly according to the search queries used as shown below.

Frequency of patent applications

<table>
<tr><th>Research equation</th><th>USPTO</th><th>E1 or E2 or E3</th><th>E1 or E2 or E3 or E4</th><th>EPO_WO</th><th>E1 or E2 or E3</th><th>E1 or E2 or E3 or E4</th></tr>
<tr><td>Equation 1. Glanzel et al.</td><td>1454</td><td rowspan="3">2379</td><td rowspan="4">2804</td><td>2214</td><td rowspan="3">3788</td><td rowspan="4">4441</td></tr>
<tr><td>Equation 2. Muller</td><td>1431</td><td>2250</td></tr>
<tr><td>Equation 3. Porter et al.</td><td>1731</td><td>2714</td></tr>
<tr><td>Equation 4. Mogoutov and Kahane</td><td>1931</td><td></td><td>3020</td><td></td></tr>
</table>

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The evolution of the patent base using the largest search strategy 'E1 or E2 or E3 or E4' is given by figure A6 in appendix. It must be noted that the number of patent applications may not be complete for the last year when the figure dips. What is most interesting – is that according to the larger search strategy used – the image obtained is that India has been building a knowledge base relevant to nanotechnology since the mid-1970s, though the take off has really occurred after the adoption of liberalisation during the mid-1990s.

Applying a cluster analysis, followed by a correspondence analysis using the program Alceste as before, to the patent summary (resumé) of the corpus of patent applications extracted from the USPTO using the equation E1 or E2 or E3 or E4, crossed with India as the country of priority, revealed a three-point focus.

The first and most important focal point is 'nanopolymers' and 'nanocatalysis' which we attribute to the Indian public laboratories.

The second focal point is 'nanopharma' or applications of NST to the pharmaceutical sector. This is confirmed by the unique presence of Indian pharmaceutical firms (rather than ICT or other sector firms) in the patent corpus specific to NST evoked earlier in this section.

The third focal point is 'nanoelectronics' again probably accounted by the inventive activity of the Indian public laboratories.

3.3 New Firms and new products

At the moment it is not possible to have a clear idea of how many firms are exactly commercializing nanotech based products or services in India. But compiling the existing information we can have an idea of what kinds of commercialization activity is taking place. Our results reveal two interesting facts:

- Incumbent biotech firms are also adopting the ‘nano’ brand-imaging to commercialize their innovations such as new drug delivery systems. Indeed, most biotech applications can qualify for being nano also. Similarly, incumbent chemicals and software companies are branching into nano.
- New firms are marking the terrain of nano-materials and some of them are spin-offs from academic institutions (e.g. Monad nanotech set up by Professor Sharon Maheshwar from IIT, Mumbai; Innovations Unified Technologies set up by IIT Mumbai graduates).

Type of Production/Service provision	**Examples of firms**
Manufacturing of nanoparticles or nano-tubes or specialized nanomaterials	Monad nanotech (first to produce carbon nanotubes in India) NanoBio Chemicals NanoFactor Materials Technologies Nanoshel Neo-Ecosystems Nanocet Auto Fibre Craft (AFC) Innovations Unified Technologies
Nano applications Nano Silica products	Bee Chems
Simulation Software Products	Cranes Software
Drug delivery systems	Dabur Pharma, Life care innovations Bharath Biotech
Catalysts and speciality chemicals	Micromaterials (India) Mp3s Nanotechnology
Contract Research	Nano Cutting Edge Technology NanoCET Velbionanotech
Education for industrialists/industries	Eris Technologies
Distributor of instruments	Icon Analytical Equipment
Business consulting	U-Shu Nanotech Yashnanotech

Compiled by authors from internet sources[8] and from Sen (2008)

4. Challenges for the future

From the preceding sections it is clear that India, like most emerging economies, can pursue a combination of three strategies: (i) compete as first innovators; (ii) cooperate with global leaders in the latter's innovation strategies by becoming a cog in their wheel and try to learn at the same time; or (iii) pursue a 'wait and see' policy and focus on future manufacture of generics. At the moment, we see some evidence of the first and third strategies mostly. Some pro-poor innovations have emerged but which are not likely to be patented or licensed. There are some distributors and manufacturers of nanomaterials, which could pave the way for the future generics capabilities. In the specific field of bio-nano, so simply biotechnology, there are examples of all three strategies. Still, India is at cross-roads as the direction of activity is not yet completely set. Therefore, we turn to the challenges at hand and then spell out our policy recommendations for the same.

4.1 Decisions at cross-roads

There are two kinds of decisions that increase in terms of the scope of their consequences because of the nature of their 'irreversibility'. First, and most reversible, are the focus of public funding; second, and less reversible come a set of 'regulatory changes' that are in the pipeline. Both these will impact the strategies being pursued by the various actors in the NST innovation system and hence the final outcomes.

5.1.1 Why not take the path less travelled and more narrow?

As mentioned earlier nanotechnology holds promise both for economic growth and inclusive development. The former may be served by manufacturing of different types of nanomaterials and nanodevices (e.g. new drug delivery systems) while the latter may be addressed by new technologies for remediation of water and soil, capture of solar energy and increasing of agricultural productivity etc. At the moment public investment is being geared to create scientific and technological capabilities rather than to capture specific market niches or satisfy specific social needs. Here the question is – given the present capabilities and the retard vis-à-vis the nano leaders, both in terms of financial and technological capacities, is it better to leave market development to individual (private or public) initiatives? Why not go in for a concerted quasi-mission mode strategy of focussing on a set of potentially high-growth niche products/processes for mainstream national and international markets and a few targeted and selected disruptive pro-poor innovations again both for domestic as well as international markets in other developing countries?

Indeed, since so many follower countries including India seem to be so set on imitating to a large extent the US model and strategies, it is useful to keep in mind some notes on the US system of innovation. Till the mid 1980s the innovation system in the US was largely driven by 'visions of war' – in that case the cold war. Then during the 1990s fund raising for biotechnology was largely pushed by the 'war against cancer'. In the new millennium, the 'fight against climate change' is the reining argument to channel funds into

[8] http://www.nanowerk.com/nanotechnology/nanomaterial/commercial_country.php?country=India

nanotechnology (Newfield, 2010). Why not use the old motto of ‘war against poverty’ or ‘Garibi Hatao’ as India’s flag to target at least some niches for investment in nanotechnology on a war-footing?

5.1.2 A Bayh-Dole Act for India?

An important development that is bound to impact patenting activity in nanotechnology, is the drawing up of “The Protection and Utilization of Publicly Funded Intellectual Property Bill, 2008,” commonly known as the Indian Bayh-Dole act. The act is currently under review by the Parliamentary Standing Committee on Science, Technology, Environment and Forests. The bill aims to codify standard rules and protocols for ownership and servicing of intellectual property resulting from public funded research. Although the bill mirrors its American counterpart in several ways, it also provides additional ‘india-first’ provisions, including local manufacturing requirements for products based on IP licensed from such public funded research (Sampat, 2009). Another important aspect of the bill is that it issues strong penalties against non- patenting of all public funded research.

Given the combination of rewards and penalties embedded in the bill and the large quantum of public funding in nanotechnology, the enactment of this act is expected to increase patenting by public researchers in the hope that they may also influence the pace of commercialization of nanotechnology based products that may result from such IP.

There are two points to be noted. First, patent applications are costly to obtain and maintain. They generate revenue for public research organizations only if they can be licensed out to users. Second, in order to generate such licensing revenue it will be necessary for public research institutions to be equipped with efficient technology transfer units to which researchers at all levels can go for help without going through a bureaucratic process. This is not the case at the moment. Therefore, the rush to patent might results in a glut of sitting patents that eat up tax-payer’s funds for maintenance. The CSIR, which between 2002 and 2006, obtained more patents from the US patent office than the total number granted to its counterparts in France, Japan and Germany combined has already been criticized, because the revenues generated by its patents do not cover by any means the funds required to maintain them (Jayaraman, 2006).

5.1.3 : To promote “knowledge commons” or “knowledge anti-commons”?

Another downside of the pending Indian Bayh-Dole act is that the patent applications could be oblivious to whether patents are actually required in that area or whether other alternatives like open source exist. In the case of nanotechnology which is still at a nascent stage, creation of such compulsory system of patenting may hamper rather than promote technology transfer by critically limiting the circulation of ideas in the public domain.

Some analysts suggest that enough flexibilities exist within the current patent regime (including post-grant opposition, research exemption and compulsory licensing) for not allowing the access to patented information to be impeded by patent thickets and overly broad patents (Barpujari, 2010). However, efficient exploitation of such flexibilities is far from clear (e.g. compulsory licensing is possible only under national emergencies) and at least for essential goods like medicines, food, water and habitation it would be worthwhile to push the frontiers of the ‘knowledge commons’.

There is a choice – should India promote intensive 'privatization of knowledge' and try to compete with world leaders or should it be the leader of the underdogs and promote the 'global commons'? Should India produce knowledge and technology in nanotech for the global market or a global "technological commons," which is more focused on the specific needs of developing countries – especially since most of the research is being funded by the Indian Government?[9]

5.1.4: Should there be a specific risk regulation for nanotechnology based products and processes?

Before making any specific suggestions with regard to risk regulation, we would like to express the following caveats. First, when risk regulation issues regarding nanotechnologies are discussed – the reference is to nanomaterials and nanoparticles. So essentially there are no generic risks that are associated with all nanotechnologies – potential risks may emanate from nanomaterials and nanoparticles and this will further depend on the manner of use – or the way nanotechnology is used within products and applications. In that sense, it is not practical and therefore unlikely that a uniform regulatory approach to all kinds of nanotechnologies will be adopted. However, at the general policy level and given the potential environmental and health risks of some nanomaterials – guidelines for safe handling of nanomaterials for laboratory use may be developed in the first stage. Two kinds of critical inputs can guide regulation: (i) the nature of products and applications using nanomaterials; and (ii) the toxicological protocols that will guide risk assessment exercises that may be mandated for these kinds of products and applications.

The lack of regulation specific to nanotechnology seems to be leading to some optimistic views that seem misplaced. For example, Sen (2008) sees nano-material as the first domain of conquest for developing countries, including India and while this is widely accepted, the reasoning for the same is questioned. According to him the production of nanomaterials in India offers the advantage not being subject to regulation with respect to toxicity, because prevalent rules are based on the concentration of a toxic material with the respect to the body weight of the target group, and by definition nanomaterials are not in this range. This in theory could lead to the production and distribution of toxic materials – in a way similar to asbestos sheets – which are banned in developed countries but continue to be sold in emerging economies like India despite clear confirmation that they increase the risk of getting cancer.

5.1.5 Again on Regulation – should there be new product categories?

As table 2 indicated at present there are a number of laws which could apply to any new NST based products that enter the market. India does have a well demarcated system of regulatory responsibilities and a huge reservoir of regulatory experience. The drafting of legislation, rules or regulations to govern nanomaterials within specific fields of applications would necessarily benefit from the different aspects of regulatory governance that have been functioning in the protection of health and environment especially vis-à-vis other technological sectors like biotechnology. For reasons of regulatory economy, (Srivastava and Chowdhury, 2008) the necessary first step is to consider the adaptability of existing regulatory regime. The architecture of the current regime (environmental protection, product safety and quality of cosmetics, medicinal products, and occupational health) will limit the number of

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[9] I would like to thank Dr. W. Patrick McCray for summarizing my ideas so succinctly after a presentation – see http://www.scienceprogress.org/2010/05/re-thinking-innovation/

regulatory choices available to the regulators in addressing the potential risks from nanomaterials – limitations of architecture. The regulators will therefore have to choose between incremental changes within the existing regime or development of a separate product category or even ingredients based category – for instance rules for all nanosilver particles based products – contingent on the nature and scale of product development and the potential harm that may result from them. The collective regulatory experience of these ministries in earlier comparable situations – like for instance in biotechnology- is therefore invaluable in policymaking in this field.

As an illustration, it is to be noted that the Medical Devices Regulation Bill, of 2006 is currently pending in the Parliament. This bill aims to provide for a comprehensive coverage of the design, manufacture, packaging, labelling, import, sale, usage and disposal of medical devices. Under the present Drugs and Cosmetics Act, 1940, regulatory standards for both medical devices and drugs are the same, unlike in the USA and Europe. Therefore, if this Bill is enacted it is expected to reflect the practice wherein the threshold for regulation is much lower for drugs than for medical devices. Such a differentiation is of itself not problematic. However, in the case of combination products (combine features of both medical devices and drugs) that use nanomaterials or nanoparticles, the question is whether all such applications should be regulated in a similar manner to drugs that use nanomaterials? In 2009, the Drugs Controller General of India, recalled the nano-based Albupax breast cancer drug and ordered further toxicological tests amidst fears that it can cause liver damage. However, the health ministry has overturned this order of the DGCI.

5.1.6 Should a new patent classification specific to nano be introduced?

Both, the U.S. Patent and Trademark Office (USPTO) and the European Patent Office (EPO) have developed nanoclassifications: 977 and Y01N respectively. However, for the moment the Controller General of Patents, Trademarks and Designs (CPGTDM) in India has not developed a classification specific to NST. Given that nanotechnology is an emerging area, it is critical that the scope of the term 'nano' be clarified so as to allow the verification of claims of novelty in patent applications. However this seems to be unlikely to happen in the short term, given that the patent office is facing a major human resource deficit in 'examiners' and there are a limited number of examiners in the field of agriculture, biotechnology and chemistry.[10] This could become a major impediment to developing any capability for specialized examination of nanotechnology patents.

5.2 Policy Recommendations

To conclude, the usual complaint voiced by Indian scientists, industry associations, firms and policy makers themselves, is that India lags behind because enough funds are not being invested into nanotechnology. They are of course justified in the sense that India is spending far less than other leaders like the USA or China. For instance, the starting investment of the USA in 2001 was $450 million, by 2005 China was spending about $250 million per year, while India could invest only $22.8 million from 2002-2007 (Michelson, 2008). However, it is not at all clear if 'more is always better' i.e. if throwing more money into the public research system or firms would really yield proportionate results. A better re-

[10] CPGTDM (2007) Annual Report of the Office of the Controller General of Patents, Designs, Trademarks and Geographical Indications, Intellectual Property System Training Institute and Patent Information System, 2006-2007.

alignment and functioning of existing capabilities may also be required for improving outcomes and for this we propose the following.

5.2.1 Have the research funding bodies coordinate more and better

The main program through which public research funding is disbursed is through the Nano Mission and the DST is the focal actor with the overall mandate of nanotechnology development in India. However, there are other departments (e.g. DAE, DBT, DSIR through the various CSIR labs) and various ministries that are supporting specific research programs (recall section 2). As a result NST research in India can be characterised as diffused. This is of itself not a problem, especially in the initial stages of technology development – wherein basic research is funded. This is especially true for nanotechnology, which is a platform technology that may enable a number of applications across sectors. However, it is important that effective linkages between the various ministries involved in funding research programs are made, so as to avoid duplication of effort and provide opportunities to explore synergy between the various research groups.

The other important aspect of public research funding is to provide a balance between basic research, applications funding and toxicological research. Given that the number of nanoscience applications continues to increase, the toxicological effects of nanomaterials across products and also their cumulative impact on the environment needs to be investigated as a priority. For instance, actors such as the MoHFW and CSIR are involved with both applications and toxicology research while others such as the IITR, NIPER, IICT and ICMR are mainly pursuing toxicological research. Effective external and internal linkages must be formed between these bodies because both types of actors can learn from developments in each of their activities.

5.2 Expand the partners forming the Nano mission Strategically speaking, the improvement of linkages between the actors involved in public research funding, technology development and technology transfer, and risk regulation is critical to the future success of nanotechnology in India. Thus, it is necessary that the Nano Mission include representatives of all the actors involved in basic research, applications and toxicological research described above. Tell me please who is NOT included as of now in actors involved in building of scientific capabilties?

Moreover, there are other actors engaged in metrology, patents and technology transfer and who are also involved in nanotechnology policy without being present in the Nano mission. For instance, the BIS is currently working on standardization aspects that will have implications for both product development and risk assessment. It also liaises with the ISO, and therefore is the primary forum through which Indian research scientists in this field can participate in the work being undertaken by the ISO. But, BIS is not in the Nano mission, while it should be. Likewise, the major actors undertaking toxicology research, such as IITR, NIPER and ICMR, should also participate in the BIS's MHD21 committee.

Finally, the Ministries MOEF, MoHFW, MCF and the MoLE which are the leading actors overseeing regulatory mandates of direct relevance to nanotechnologies have their strong domain expertise and considerable regulatory experience. At an overall level, all these four Ministries should become members of the Nano Mission. This will ensure that the ministries are aware of the kinds of products and applications that are expected to be launched in the market. Linkages with those research institutes undertaking toxicology research such as IITR, IICT, NIPER and ICMR and these ministries must also be strengthened.

5.2.3 Have more services to facilitate the creation of start-ups

Given their expertise and existing capacities, an extended role for the NRDC and TIFAC in providing support services for research groups and start-ups that are receiving public funding can be justified. These actors are well placed to act as intermediaries between the applicants and the patent office in providing technical inputs on the nature and scope and quality of patents, and the emerging field of patenting activities.

Information generated through patent tracking in India and abroad can be used by policymakers to provide strategic support services and make public research investments in specific sectors. Industry associations such as the CII, ASSOCHAM and FICCI, can also become key partners in this initiative. This way the design for 'targeting' investment will become more rational.

5.2.4 Refine incentives for performance in academic establishments A case in point in China which achieved its spectacular increase in nano-publications not only because of a larger investment but also it carried out a thorough reform and de-politisation of its academic system and made both recruitments and promotions more transparent and linked to scientific performance (Huang and Wu, 2010). In India, along with the present system of extensive and intensive positive discrimination to promote inclusive education, especially at the higher levels, which has yielded very good results, there must also be a place for poles of excellence which are governed by merit in terms of both recruitment and promotion. Furthermore, instead of linking promotions and institutional funding to patenting by researchers, they must be linked to licensing revenues earned. The point is not to generate patent applications but to raise licensing revenues which will both diffuse the new technology in the market and support the research institutions concerned. Finally, less than 22% of the publications are in collaboration with non-Indian institutions, and this can also be increased to augment the learning in NST.

6. Conclusions

The present article examined the role of State policy, public and private investment in NST in India in an attempt to answer the central question: To what extent has the present Indian engagement in NST enabled India to contribute to income and employment generation, inclusive development, and ensure an international leadership in selected niches?

We showed that India like other countries with established scientific capabilities is investing more in nanotechnology than it has in any other platform technology. Not only are upstream scientific and technological capabilities being strengthened, but attempts are also being made to make the regulation system effective, protecting both firm and consumer interests. In the 'knowledge market' India has clearly made a dent in terms of its scientific publications (with the main focus being on nanomaterials), in the 'technology market' its patenting performance though not extraordinary is respectable compared to other emerging economies spending similar amounts – see figure A7 in appendix (with the principle focus on nanopolymers and nanocatalysts). In the 'final products' market some biotech and ICT incumbents are moving towards nano but the bulk of the new firms are in the field of nanomaterials. These achievements are particularly noteworthy given the much smaller quantity of funds invested by the State and individual organizations as compared to the international leaders in nanotechnology.

However, even given these initial optimistic results, the moot question remains: is it in the interests of Indian citizens (and especially the poor), that India's science and innovation, and intellectual property policies are increasingly being modeled on the lines of developed countries – especially the United States—so as to attempt to compete or collaborate with them? Does catching-up necessarily have to involve quasi-imitation of policy or market design of the nano-leaders? Do the innovation needs of developing countries like India map onto the priorities of countries such as the United States or Japan? Would India's investment for future nanotech innovation be better spent if at least a part of it focused along a 'mission mode' on alleviating current environmental problems and agricultural productivity? The answers to such questions will depend on the visions and strategies pursued by the different actors of the Indian system of innovation.

Our analysis questions the widely held premise of the macroeconomic theories of growth as well as the meso-economic theories of "systems of innovation" and the "catching-up literature" that if the State invests in the development of social capabilities and scientific capabilities, and facilitates the construction of technological capabilities in firms, then industrial capacity will be constructed, and then somehow through the trickle down effect, with augmentation of income and employment, poverty will be reduced. With the world-wide ICT and biotechnology revolutions, some more truisms can be added to this basic assumption. Some of these are: more the public investment higher the returns (i.e. more is always better!); every country should have its own Bayh-Dohl's law; TRIPS is good for international developing technology markets and venture capital is essential for hi-tech sector growth.

In contrast, the present paper argues that it may not make sense to catch-up with developed countries in terms of policy or market design. Simply crying for more public investment in an emerging sector like NST without a continuous institutional reform may not yield the highest returns. It may not make sense to push for more and more privatization of knowledge. A venture capital market as is present in the US is unlikely to be a replicable institution – so why try to replicate it? Having scientific publications does not guarantee patents, having patents does not ensure product or process innovations that reach the market, and finally having innovation led economic growth does not imply that the lives of the poor will be proportionately better off.

Therefore, rather than playing a pure strategy of public investment for private economic growth, if a mixed strategy is played, with public investment for both economic growth and inclusive development, the returns are likely to be higher. To achieve either of the two (growth or development) and especially the latter objective, the stakeholders must zero in on a set of 'concrete targets' to be accomplished through public institutions and public-private partnerships – but this must be on a 'mission mode' like it is for 'space technology' and as it was for achieving the spectacular public sector results as under the 'Green Revolution' rather than being left to individual initiatives.

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APPENDIX

Figure A1

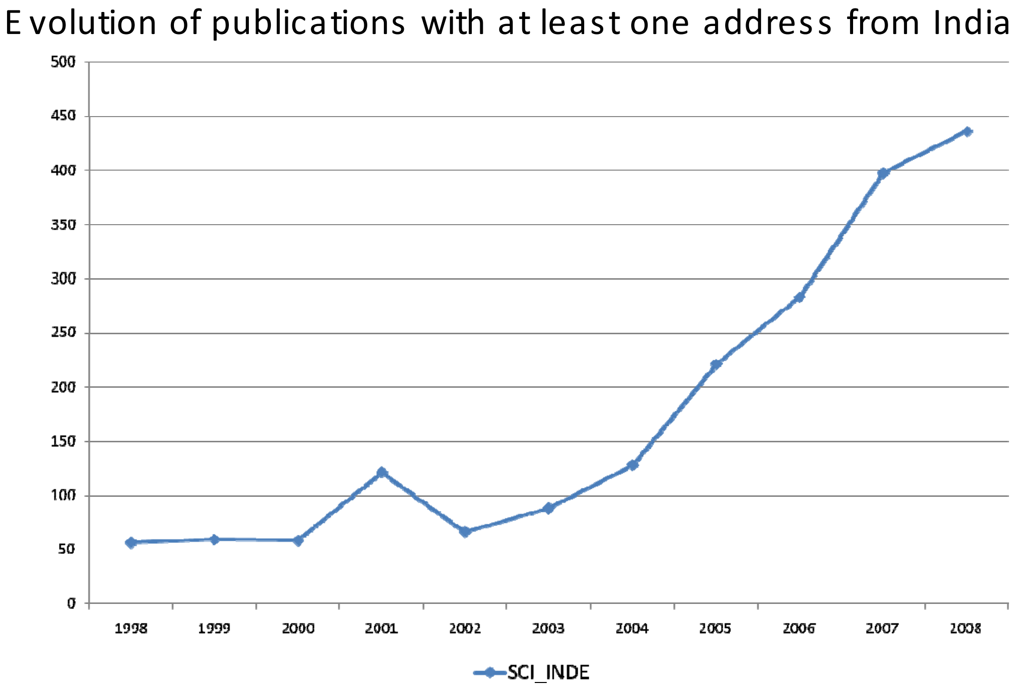
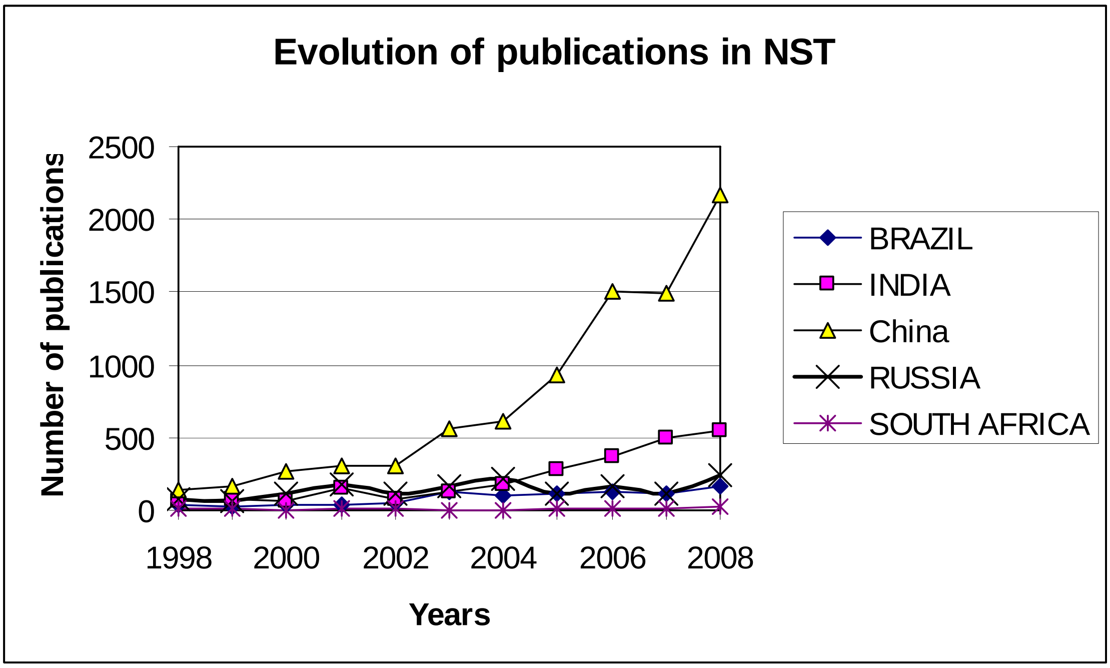


Figure A2



Tables A1 and A2

Journals of JCR 2007 Nanoscience & Nanotechnology in which Indian institutions have published

Frequency	Title of the journal
591	MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROSTRUCTURE AND PROCESSING
290	JOURNAL OF NANOSCIENCE AND NANOTECHNOLOGY
173	SCRIPTA MATERIALIA
144	NANOTECHNOLOGY
132	SYNTHESIS AND REACTIVITY IN INORGANIC METAL-ORGANIC AND NANO-METAL CHEMISTRY
116	MICROPOROUS AND MESOPOROUS MATERIALS
93	PHYSICA E-LOW-DIMENSIONAL SYSTEMS & NANOSTRUCTURES
59	MICROELECTRONICS JOURNAL
46	JOURNAL OF NANOPARTICLE RESEARCH
44	BIOSENSORS & BIOELECTRONICS
32	JOURNAL OF COMPUTATIONAL AND THEORETICAL NANOSCIENCE
30	MICROELECTRONIC ENGINEERING
25	NANOSCALE RESEARCH LETTERS
14	JOURNAL OF MICROMECHANICS AND MICROENGINEERING
14	JOURNAL OF VACUUM SCIENCE & TECHNOLOGY B
13	MICROELECTRONICS RELIABILITY
12	SMALL

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Journals of JCR 2007 Nanoscience & Nanotechnology in which Indian institutions have published

Frequency	Title of the journal
12	NANO LETTERS
9	FULLERENES NANOTUBES AND CARBON NANOSTRUCTURES
9	JOURNAL OF NANOELECTRONICS AND OPTOELECTRONICS
7	JOURNAL OF EXPERIMENTAL NANOSCIENCE
7	CURRENT NANOSCIENCE
7	ACS NANO
5	MICROFLUIDICS AND NANOFLUIDICS
5	IEEE TRANSACTIONS ON NANOTECHNOLOGY
4	JOURNAL OF MICRO-NANOLITHOGRAPHY MEMS AND MOEMS
4	LAB ON A CHIP
3	JOURNAL OF MICROLITHOGRAPHY MICROFABRICATION AND MICROSYSTEMS
3	MICROSYSTEM TECHNOLOGIES-MICRO-AND NANOSYSTEMS-INFORMATION STORAGE AND PROCESSING SYSTEMS
2	INTERNATIONAL JOURNAL OF NANOMEDICINE
2	IEEE TRANSACTIONS ON NANOBIOSCIENCE
2	PHOTONICS AND NANOSTRUCTURES-FUNDAMENTALS AND APPLICATIONS
2	BIOMEDICAL MICRODEVICES
1	REVIEWS ON ADVANCED MATERIALS SCIENCE
1	MICRO & NANO LETTERS
1	PLASMONICS

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Table A3: Addresses of leading authors

Author	Number of articles in which name appears	Address
Das, S	39	Natl Met Lab, Jamshedpur 831007, Bihar, India
Kumar, A	29	Univ Delhi, Dept Elect Sci, Semicond Devices Res Lab, New Delhi 110021, India
Chaudhuri, S	29	Indian Assoc Cultivat Sci, Dept Mat Sci, Calcutta 700032, W Bengal, India
Tyagi, AK	29	Bhabha Atom Res Ctr, Div Chem, Bombay 400085, Maharashtra, India
Murty, BS	28	Indian Inst Technol, Dept Met & Mat Engn, Kharagpur 721302, W Bengal, India
Raj, B	27	Indira Gandhi Ctr Atom Res, Met & Mat Grp, Kalpakkam 603102, Tamil Nadu, India
Gupta, RS	26	Univ Delhi, Dept Elect Sci, Semicond Devices Res Lab, New Delhi 110021, India
Dey, GK	25	Bhabha Atom Res Ctr, Div Mat Sci, Bombay 400085, Maharashtra, India
Sastry, M	22	Natl Chem Lab, Mat Chem Div, Pune 411008, Maharashtra, India
Chattopadhyay, K	22	Indian Inst Sci, Dept Met, Bangalore 560012, Karnataka, India

Table A4: Countries featuring in the 533 publications in which there is at least one author with address outside India

Country of collaboration	Number of addresses	Country of collaboration	Number of addresses
India	665	Brazil	5
USA	188	Chile	5
Japan	127	Switzerland	4
Germany	111	Sweden	4
SOUTH KOREA	66	Austria	4
France	45	Finland	4
England	29	Mexico	4
Canada	27	Israel	3
Peoples R China	23	Denmark	2
Taiwan	22	Thailand	2
Singapore	19	Iceland	2
Italy	19	Norway	2
Netherlands	13	Egypt	2
Australia	13	Slovakia	2
SOUTH AFRICA	11	Poland	2
Belgium	11	Oman	1
Hungary	8	Senegal	1
Ireland	7	Czech Republic	1
Portugal	7	New Zealand	1
Russia	6	Algeria	1
Spain	5	Slovenia	1
Iran	5	Nepal	1

Figure A3

Network of institutions with four or more collaborations

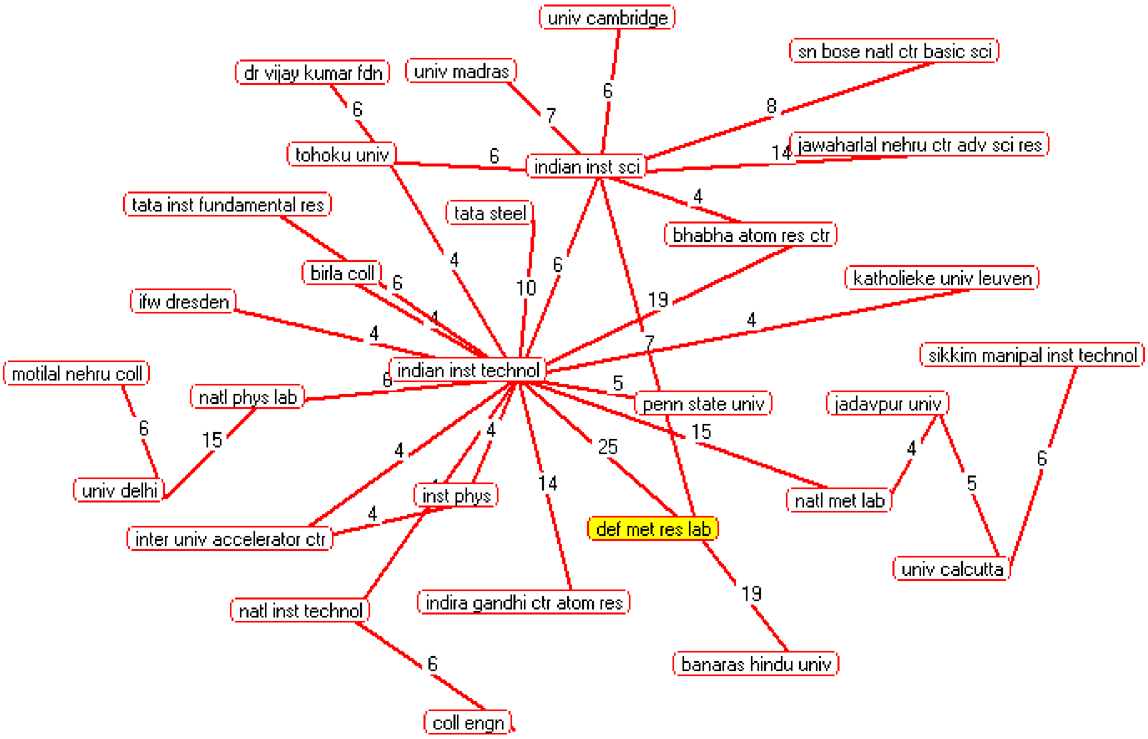


Figure A4

Network of institutions with four or more collaborations

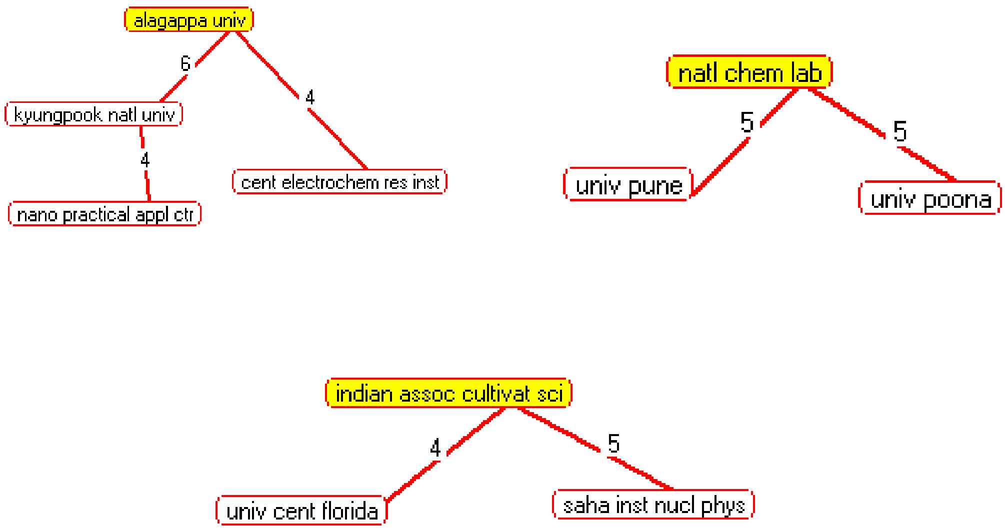
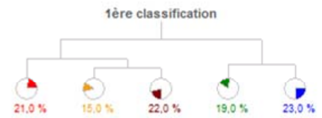


Figure A5

The main clusters obtained and their weight in the corpus of publications



Classe 1		
Forme	khi2	Eff.
complexe	416	155
acid	397	217
act	313	173
catalyst	295	143
mesoporo	254	82
zeolite	220	73
enzyme	205	74
immobil	195	68
catalytic	193	62
ligand	187	75
react	181	213
select	176	104
drug	172	70
adsorpt	157	60
electrode	153	77
biosensor	131	48
ion	122	148
molecule	118	75
framework	115	46
deliver	106	31
group	102	61
molecular	102	59
silica	100	65
liposome	100	44
desorption	99	34
complex	97	69
gold	91	101
Variable	khi2	Eff.

Classe 3		
Forme	khi2	Eff.
nanotube	264	124
powder	239	182
synthesiz	186	140
ray	179	179
nm	175	170
fe2O3	160	47
mill	157	114
nitrate	153	38
diffract	151	142
transmiss	140	105
particle	137	231
combust	136	37
microscop	129	161
size	114	266
mossbaue	107	27
scann	105	91
nanosize	93	24
electron	91	203
nanopartic	88	139
carbon	80	123
magnet	79	101
hydroxide	75	23
ball	73	51
fuel	73	30
microwave	71	30
diameter	68	67
spectroso	68	103
Variable	khi2	Eff.

Classe 4		
Forme	khi2	Eff.
film	766	504
optical	282	176
photolumir	265	90
thin	258	149
nm	255	342
absorpt	252	146
band	250	134
quantum	228	97
nanocryst	227	110
zno	223	155
shift	219	101
emission	205	134
zns	201	81
blue	187	69
dope	161	94
cds	157	74
ev	149	56
gap	148	66
sputter	148	62
deposit	146	175
fluence	121	43
substrate	120	139
confine	115	56
grow	106	78
size	103	283
spectra	102	92
dielectric	99	84
Variable	khi2	Eff.

Classe 2		
Forme	khi2	Eff.
strain	357	263
rate	348	283
stress	248	189
flow	211	111
wear	205	195
frict	183	71
slide	150	65
test	140	131
deform	129	95
model	124	114
plastic	118	45
experimen	114	87
specimen	110	79
load	100	104
notche	100	31
regime	100	50
crack	98	90
behaviour	90	94
map	88	31
instabilit	88	31
predict	87	43
shear	85	54
equation	84	41
epoxy	83	34
fail	77	36
coefficien	75	52
lubric	73	26
Variable	khi2	Eff.

Classe 5		
Forme	khi2	Eff.
alloy	1268	797
microstruc	389	216
roll	346	164
strength	337	248
precipit	319	209
al	288	217
tensile	280	168
hardness	232	125
treatment	204	139
steel	198	206
improve	190	131
ti	187	118
weld	186	159
cast	185	106
aged	182	80
phase	176	375
wt	164	117
ductility	158	68
addition	156	133
cold	151	72
grain	148	224
ageing	144	58
mechan	143	202
treat	141	95
compos	140	255
heat	134	171
alpha	134	136
Variable	khi2	Eff.

Figure A6

Evolution of patent applications in nano classes in USPTO and EPO_WO using E1 or E2 or E3 or E4

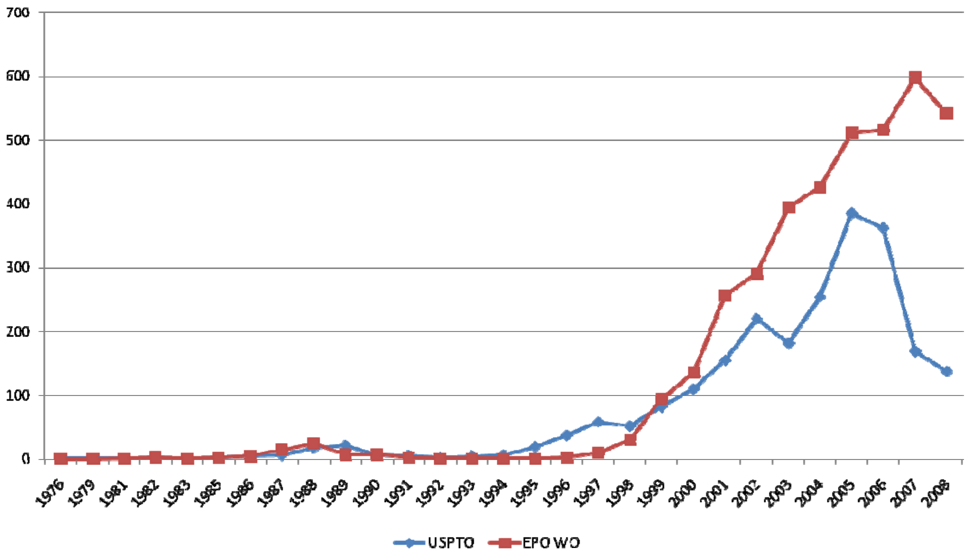
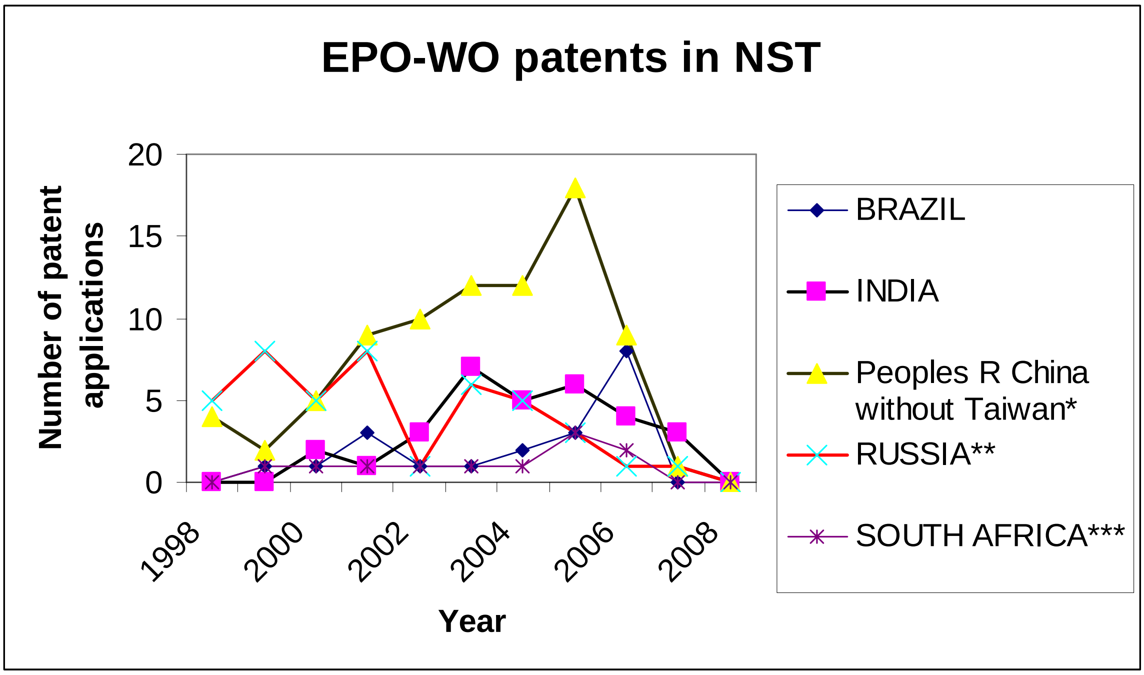


Figure A7



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