Missing Gaps in Indian Nanotechnology Development: Exploring Effective Policy Interventions for Innovation and Commercialisation

Sujit Bhattacharya

National Institute of Science Technology and Development Studies and Academy of Scientific Research and Innovation
Pusa Campus, K. S. Krishnan Marg
New Delhi- 110012
Email: Sujit@nistads.res.in; sujit_academic@yahoo.com

Introduction

Nanotechnology is promising to be the "transformative" technology of the 21st century with its boundless potential to revolutionize a wide range of industries, perceived to provide novel innovative solutions to complex technological problems, create functional and highly differentiated products in high technologies as well as in areas that are of pressing concerns in developing and improvised economies, i.e., environment, water purification, agriculture, energy and in a host of other products and services. This promise has led to strong public push by different countries to create capabilities for exploiting this technology. Almost no other field has obtained as much public investment in R&D in such a short time as this field. This investment pattern is not restricted to North economies. BRICKS countries, and other scientifically proficient countries such as Singapore and Taiwan are making huge investments in this field (Bhattacharya et. al. 2012).

The National Nanotechnology Initiative launched by US Government in 2001 as a mission mode multi-agency programme was a very well articulated programme providing a roadmap/vision for development of this area in different sectors with an underlying belief that this technology will create US leadership in different industries. Strongly influenced by the US model, different countries started dedicated programs with liberal public funding support. Some visible outcomes of global investment in nanotechnology can be seen. Huge investment provided the impetus to create advanced instruments for engineering nano-materials. Nanotechnology has emerged among the most active area of research with exponential increase in research papers, patent filing have been very aggressive in influential patent offices, and standard making has led to the joining of different stakeholders with strategic goals (Coccia, 2012). Huge public investment in nanotechnology is leading to increasing demand for promising applications. Some of the “promises” are beginning to take shape with nanotechnology emerging as an enabling technology in improving the functionality of processes and products in various sectors and areas of developmental challenges (see for PEN). However, nanotechnology is still a far distance from its perceived promise.

The present debate on nanotechnology has shifted more towards innovation and commercialization issues (Genet, et. al. 2012). Also regulatory issues, issues of patenting and standardization, EHS/ELSI (Environment, Health, Safety issues; and Ethical, Legal, Societal Implication) concerns have emerged. Thus in the present context, the key challenge is in exploiting promising research; developing novel strategies that provide novel pathways for successful translation. Unlike other key technologies, emerging economies have been actively involved in developing capability in this key field. However, translational research (converting “blue sky” research into a tradable commodity) has been an outlier in spite of promising research seen in emerging economies. What would be the effective policy interventions to bridge the “valley of death” remains a puzzle for policymakers, particularly in emerging economies? (Ramani, 2014).

The study examines this ‘puzzle’ in the Indian context i.e. what types of policy interventions can help in exploitation of nanotechnology research for addressing socio-economic challenges.

Conceptual Framework of the Study

The study applies National System of Innovation (NSI) approach to investigate the Indian nanotechnology capabilities and strategies. The NSI approach is embedded within the Innovation System (IS) approach. The core elements of IS approach is that (a) national systems differ in terms of specialization in production, trade and knowledge (Archibugi and Pianta 1992, Nelson 1993), (b) elements of knowledge important for innovation performance are localized and not easily moved from one place to another, (c) the importance of interactions and relationships; relationships seen as carriers of knowledge and interactions as processes where new knowledge is produced and learnt (Dosi 1999, Lundvall, 1992). NSI can simply be seen as applying IS approach when it is territorially bounded within the national system (see for example Verblane & Tamm, 2012). NSI allows a useful analytical framework to push the debate of catch-up forward.

NSI accommodates the catch-up thesis (Gerschenkron 1962) that technology catching-up cannot be taken for granted because a variety of necessary and complementary capabilities may be needed for effective absorption of existing technological knowledge, even if freely available. Further the notion of technology gap as argued by evolutionary economist (see for example Verspagen, 1992), provides a useful hyphenation to catch-up theory and has influenced the NSI thesis. The technology gap hypothesis argues that if the technology gap is too large, it is difficult to absorb technology, as the conditions in the countries of origin and the countries of destination are too large. NSI assumes that the commercialisation of innovations in any country in a new science-based sector is a collective process embedded within a system specific to the country. In other words, the creation, development, adoption, and diffusion of innovations evolve as a function of the existence and functioning of networks between the state and a variety of organisations, such as firms, consumers, public laboratories, universities, financial institutions, and civic associations.

NSI analytical framework argues for creation of institutions that: promote interactions between divergent actors (government, firm, academia), and help develop capabilities and interventions that can disrupt path dependency (the inertia in the system that inhibits introduction of new technologies). However, looking from various different theoretical and conceptual frameworks one observes divergent views on public sector intervention and the extent of intervention to support innovation/innovation process. The different viewpoints converge primarily on two concepts: market and system failure. Market failure are primarily linked to the under provision of public good because of uncertainties, externalities, inability to appropriate the positive externalities of knowledge/innovation, inability to invest because of lack of private sector interest, and missing markets. The IS approach argues that markets are not the only actors in a country's economic development. Broader set of failures (system failure) has to be taken into account for public intervention, as there are other actors besides markets surrounding the innovating and economically active firms (Varblane & Tamm, 2012).

Nanotechnology in the Present Global Context

The NSI framework has played an influential role in discerning determinants for development of science-based technologies. Science based technologies disrupts the traditional models of R&D and technology transfer (Ganguli, 2013). Among others, co-production of upstream knowledge, concurrent transfer between industry and knowledge producing entities, development of consortia promoting pre-competitive collaboration drive innovation in emerging technologies (See for example Huggins & Izushi, H., 2007). Absorptive capacity is important for firms to adapt knowledge from public funded institutions (Cohen & Levinthal, 1990). Entrepreneurial activity tends to cluster in regions with experience in related sciences, in top-level universities or research institutes, or with R&D laboratories of major companies (Elias et. al. 2012). Venture capital investment is important to bring in know-how and networks and helps in communicating value proposition of applications to potential customers. Patenting is generally very aggressive in emerging technologies and becomes a big barrier for new entrants. Issues of Environment-Health-Safety (EHS)/Ethical-legal-Societal Issues (ELSI) becomes very important due to various types of uncertainties.

Nanotechnology being highly interdisciplinary and science intensive follows the above characteristics. Development of institutional mechanisms that strengthen networks between government-academia-industry-market addresses system failure. Advanced OECD countries over the years have developed institutional structures and mechanisms for successful commercialization of new technology based products. This provides them wherewithal for entering an emerging area like nanotechnology then for countries like India where the institutional mechanisms are developing.

Evidence based policy studies provide rationale for developing polices and mechanisms for strengthening research and innovation ecosystem, creating strategic roadmap and new business models for bridging the gap between laboratory and market. Recent studies show that large firms are driving nanotechnology innovation unlike biotechnology wherein dedicated biotechnology firms emerging primarily from universities drive the innovation process (OECD, 2010). Capital intensive nature of this field, large and diverse knowledge bases that exists in large firms which is a pre-requisite for technology development in this field are cited as some of the plausible reasons behind the influential role played by big firms in driving nanotechnology innovation. Another influential study (Walsh, 2002) showed that the combined R&D investments in nanotechnology by industry (primarily due to big firms involvement) have exceeded public investment in many advanced OECD countries. This is an interesting trend as private R&D investment surpassing public investment in advanced OECD countries implies positive market acceptance of nanotechnology capability. It implies nanotechnology research is demonstrating applications that if further exploited can be translated into novel products or can enhance the potentiality of existing products. Also it can be argued that advanced country markets are more receptive to nanotechnology-based applications, which is driving industry investment. This trend not observed in emerging economies mirrors the general trend in these countries of industry reluctance in investing in research and innovation. However, even in OECD countries, venture capital investment is still only a small fraction of overall investment plausibly implying that the value proposition that can be exploited is still uncertain. It also implies nanotechnology development primarily occurring in established firms.

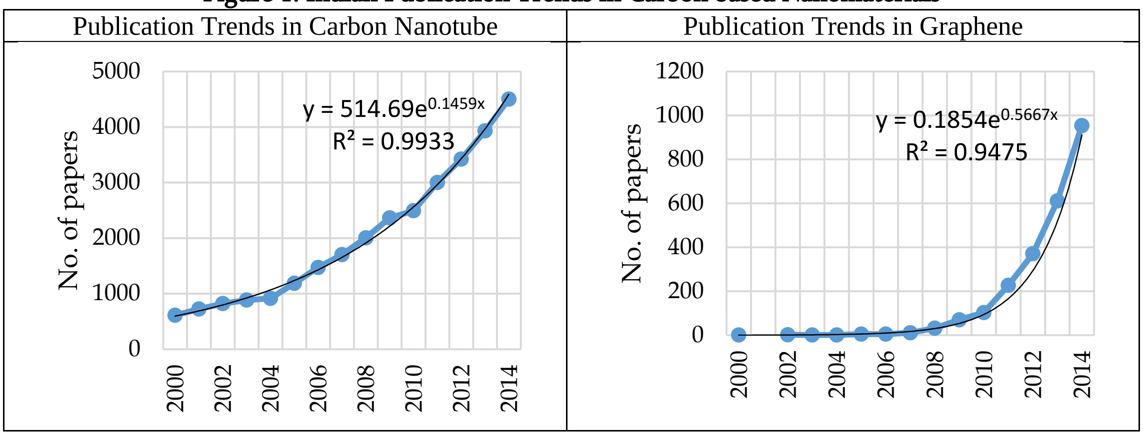
The market for nanotechnology is primarily restricted to its role in enhancing the functionality of existing products and processes. The nanotechnology market is thus primarily driven by demand for novel nano-materials that can help enhance the functionality. Nanomaterials distinguish itself due to its size, which gives it novel properties. One of the difficulties in producing nanomaterials in bulk quantity is to retain nano-size and proper storage. Thus, unlike other technologies, nano-scale provides new challenges that make the translation from laboratory to commercialization difficult. The production techniques developed in laboratory has to be scalable and industrially viable. Capturing the innovation and commercialization activity in nanotechnology is challenging due to diversity of applications and economic sectors and distributed nature of innovation. Industrial structure surrounding nanomaterials in particular due to its enabling properties and flexibility of applications tends toward s vertical disintegration of firms along the value chain (Rafols et. al. 2011)

Indian Nanotechnology Development

We identify strong Indian government support for promotion of nanotechnology. This has resulted in developing infrastructure and research community spread across different institutes in the country. The study identifies two types of initiatives by the Indian government that has led to development of nanotechnology in the country: Centers of Excellence (COEs) and Indian Nano Electronics User Program (INUP). COEs have been primarily created through mission mode programmes (NSTI: Nano Science and Technology Initiative and Nano Mission) and has helped to create dedicated infrastructure and competency in different domains within nanotechnology. INUP programme created by Department of Electronics and Information Technology (DiETY) is helping to develop the nano-electronics ecosystem. INUP provides access to sophisticated instruments and peer supports to groups involved in nano-electronics particularly to universities.

India's research competency has also significantly increased (4th rank in 2014), measured through research publications. Particularly promising is India's research activity in novel nanomaterials namely carbon nanotube and graphene (Figure 1). These two materials have shown new possibilities in developing nano-based products and enhanced enabling properties.

Figure 1: Indian Publication Trends in Carbon based Nanomaterials

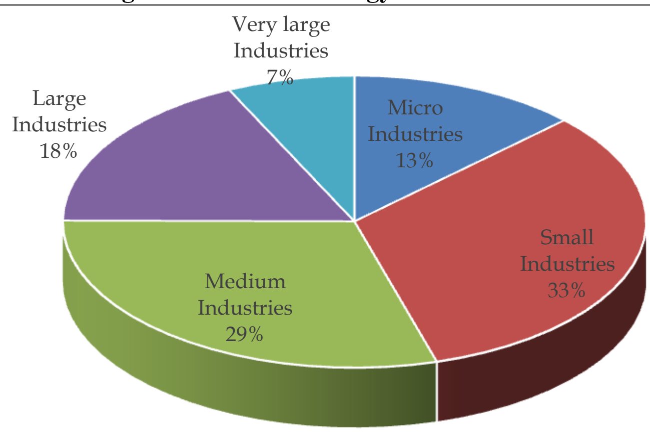


Indian Patenting trends do not match with research trends, however, it is promising to observe strong connect with patenting happening in areas of developmental concerns. Indian assignees filed 50 patents in US Patent Office (USPTO), 57 through PCT (WIPO) and 117 patents in Indian Patent Office (IPO) from year 2001-2014. Treatment and manufacture of nanostructures is the dominating area of application in all the three patent offices. Preparation of carbon-based nanomaterials is also a dominating class in IPO. Another dominating class is materials and surface sciences in IPO and WIPO. Investigation of biological and non-biological material using chemical indicators or fluorescence is also dominating in WIPO and USPTO. Some other visible classes are nano-biotechnology, drug delivery and sensing systems.

Granular investigation was undertaken by examining title and claims of filed patents in the three patent offices. In IPO, major filings are in biomedical sciences, electronics, and environment. Patents filed under biomedical applications include treatment of cancer, ocular diseases, respiratory distress, nerve disorders, and lung diseases, drug delivery systems, magnetic and fluorescent imaging, biosensors and bio-imaging. A considerable proportion of applications is also visible in energy. Patents filed in this sector include fuel cells, dye sensitized solar cells, sensors, semiconductor electronics, heat dissipation and electro-magnetic shielding. Water treatment, environment, pollution control, coatings, textiles and agriculture are some other visible application areas.

An estimated 300 firms show involvement in nanotechnology that includes Indian as well as foreign multinationals (CKMNT). 300 firms include approximately 100 foreign firms (Figure 2)

Figure 2: Nanotechnology Firms in India



Source: Author construction from India Nanotechnology Industry Directory by CKMNT. Size wise break up was done on the basis of number of employees in a firm; Micro (less than 10), Small (11-100); Medium (101-1000), Large (1001-10000), Very Large (above 10000)

A wide dispersion is seen in terms of size and operation domain and geographical location. Majority of nanotechnology firms are located in Mumbai, Pune, Bangalore, Hyderabad, Ahmadabad, Delhi (primarily NCR) and Kolkata. The presence of excellent universities and research centers seems to be a plausible driving factor for location of nanotechnology firms. This is unsurprising as this is a science based research area. Micro and small firms are basically involved in bulk production of nanomaterials while large and medium firms are exploring nanotechnology intervention in their established products. Almost all major pharmaceutical firms are active in exploring nanotechnology for drug delivery systems. Similarly all major paint companies are exploring nanomaterials applications to make efficient coatings. A few textile firms are exploring nanotechnology for enabling properties of wrinkle-free, anti-bacterial fabrics, having good elasticity and strength. One can also observe major textile Industry association ATIRA involvement in developing nano-fiber textile. The major public sector and private sector firms in petro-chemical sector (Indian Oil Corporation, Bharat Petroleum, Hindustan Petroleum, Reliance Industries Ltd.) are also seen actively exploring nanotechnology-based interventions. Other major sectors where nanotechnology firms are visible include manufacturing, industrial and laboratory chemicals, ceramic products, equipment and products like fertilizers, pesticides and machinery for agricultural purposes, healthcare and cosmetic products, and water treatment. Almost all major tyre companies in India (Ceat Tyres, JK tyres) are exploring nanotechnology-based interventions for enhancing functional properties of tyres.

Nanotechnology innovation and commercialization to a large extent is dependent on addressing risk. The risks associated with nanotechnology are due to associated 'uncertainty'. The notion of uncertainty refers to all possible, new, imaginable hazards, with which society has no or limited experience. Uncertainties make it hard to perform quantifiable risk assessment in order to establish a clear threshold value for commercialization. Uncertainty is also about limited knowledge of future product capabilities, process integration capabilities with current manufacturing practices and uncertainty about market.

Responsible technology development, EHS/ELSI aspects have not found any specific mention in the nanotechnology policy articulations in India. However, Nanomission has funded a few projects in this area. Recently, some initiatives have been taken for addressing risk issues by some institutions. ARCI has commissioned a study on impacts of its product nanosilver based water filter on environment, issues of recycling, and life cycle analysis. Indian Institute of Toxicology Research is investigating the risks of nanotechnology partly through funding of DST and

European Framework Program. Another group at CSIR-Central Food Technological Research Institute (CFTRI), Lucknow is also working in toxicity studies. National Institute of Pharmaceutical Education and Research (NIPER) is developing regulatory approval guidelines for nanotechnology based drugs and standards for toxicological tests in nano-based drug delivery systems. ELSI issues also requires more intense activity. It is restricted to only a few institutes in India. In 2010 government announced the establishment of regulatory board for nanotechnology. It is important that instituionalisation of this board takes shape.

Discussion and Conclusion

Learning from our empirical study and applying NIS framework leads us to posit some key policy interventions. A new technology has difficulties in competing with embedded technology and thus it is important to create protected space for nanotechnology. Research and development at the nanoscale requires a large degree of integration, from convergence of research disciplines in new fields of enquiry to new linkages between start-ups, regional actors and research facilities. Technology platforms development, construction and implementation of are increasingly recognized as important in enabling innovation, as a key part of business models of (high-tech) start-ups and as having dynamics and requirements of their own (Robinson et al. 2012). The key learning is that to avoid 'system failures', the government needs to develop and support institutions that can create the protected space for nanotechnology.

Nanotechnology support in India has been mainly directed to strengthen the supply side of the innovation process following a linear model of innovation. The government push has resulted in developing a strong research ecosystem. On the other hand the the policy does not provide support for scalability of R&D, industrial support for risk assessment including life cycle analysis and helping in developing niche market through fiscal and non-fiscal incentives. Essentially the demand side interventions are missing!

Emergence of Indian firms in this new technology pushes the envelope. The firm composition shows well-established firms exploring nanotechnology in creating new functionalities in their established products. Small and medium firms are in bulk nono-materials. We observe emergence of vertical as well as horizontal value chain.

A few good examples of academia-industry linkages leading to successful translation are visible. However, a closer examination shows that majority of the firms are in the lower end of the value chain, producing nano-materials. A few pharmaceutical firms are enabling their incremental innovations (primarily drug delivery platforms) with nanotechnology interventions. This scenario is similar to other domains where nanotechnology interventions is seen i.e. tyre industry, textiles, etc. However, the promises that research is showing in sensors, bio-imaging, energy efficient solutions are not addressed by Indian firms. Patent statistics indicate major gap in innovation capability.

The above findings calls for innovative policy interventions, not restricted to linear view of funding as largely the case in India. Indian firms in general have path dependency and low capability and thus cannot exploit opportunities a new technology like nanotechnology can provide fully. Thus, the nanotechnology policy intervention has to support the different stages of the innovation process and has to provide incentives for knowledge creation and exploitation, entrepreneurship and market formation.

Compared to Western Europe and the United States, risks were not debated in India for a long time. Potential risks of nanotechnologies only become an issue of debate by the end of last decade (Koen and Sujit, 2013). Among the important issue that needs deeper investigation is: How are risks and benefits taken into account? On hand a strong regulatory environment may effect time to market, marginal cost structure and allocation of resources, however, on the other hand it may contribute to consumer and investors confidence in the technology. The conflicts emerging from Genetically Modified food crops in India has primarily been due to limited involvement of diverse stakeholders and transparency in regulatory approval. As promises are beginning to be seen in nanotechnology with a few translation happening, it is important that dedicated research support is given in risk research, issues of governance and developing regulatory framework. Will a separate agency as argued by Jayanthi et. al (2012) for nanotechnology governance would be a right step in this direction? This is an aspect that requires more deliberations.

Standardisation of measurement and test methods for risk assessment of nanomaterials is still a low priority in the Indian nano funding. Nanotechnology funding towards EHS/ELSI, it is still an afterthought in the Indian case. It is estimated that almost 15% of public funding in US is in this domain. European Commission and EU framework programme has taken decisive steps towards creating institutional mechanisms to address this domain (see for example European Commission Second Regulatory Review in Nano-Materials, 2012). On the basis of their various studies and deliberations they have challenged the hypothesis that smaller means more reactive, and thus more toxic. They have called for case-to-case examination for risk assessment of nono-materials. Other scholars like Robinson (2012) argues that for innovation to succeed in areas like nanotechnology, actor alignment from the research laboratory to product development and eventual application area is necessary. They posit this alignment is difficult in emerging technologies like nanotechnology where the technology field is not well understood; the actors are not fully known, and where regulation is largely ambiguous due to various un-certainties.

To have a more informed insight and plausible input to policy makers, we conclude by providing a SWOT analysis

<table>
<tr><th>Strength</th><th>Weakness</th></tr>
<tr><td>
Research competency is visible in different domains. India emerging as the 4th most prolific producer of research papers in this area makes a strong assertion of its research capability.
Institutions INUP & COEs were developed by government for promotion of nanotechnology research have emerged as a useful model for building competency.
Star scientist with dedicated research groups
Research activity spread across multi-centre
Public push high with nanotechnology being seen as enabler for strengthening innovation across different sectors.
Patents visible in different areas particularly in areas of developmental challenges.
Products developing in different areas.
Involvement in new production methods
</td><td>
Indian nanotechnology programme primarily a publicly driven initiative with weak industry participation.
Research not linked to downstream end of the value chain. Patenting activity restricted mainly to public institutions. Expertise needs to be developed for patent examination in this field.
Lacking institutional mechanism for process scalability of R&D, Risk assessment.
Dedicated support not visible for indigenous instrument creation
Issues of EHS/ELSI do not find adequate funding support. Standard creation and adoption shows limited support.
Only initial intervention towards developing regulatory framework. No clarity whether approach would be to create sector specific regulation, or strengthening existing sectoral regulation to incorporate nanotechnology concerns or creating umbrella nanotechnology regulation framework.
Foresight exercise to strengthen existing programs or develop new roadmaps not visible.
Need for creating more awareness of nanotechnology facilities existing in the country.
</td></tr>
<tr><th>Threats</th><th>Opportunities</th></tr>
<tr><td>
Advanced OECD countries over the years
</td><td>
Opportunity to address bottom of pyramid
</td></tr>
</table>

have developed institutional structures and mechanisms for successful commercialization of new technology based products. This provides them wherewithal for entering an emerging area like nanotechnology then for countries like India where institutional mechanisms are developing. • Shrinking white spaces as nanotechnology patent thickets are emerging in different application domains. Patent entanglement may impede translation. • Regulatory issues may impede nanotechnology innovation and commercialsation. Emerging countries like India would find it more difficult to negotiate this situation. • EHS/ELSI issues may impede exploitation of research.	solutions. Efforts have been undertaken in some areas of developmental challenges (for e.g. Water, drug delivery). • White spaces exists in areas of developmental challenge. • Nanotechnology intervention can provide significant value addition to Indian products and processes. • Unmet challenges can be addressed through nanotechnology intervention.

Acknowledgement: Some findings are drawn from the policy Bulletin 'Nanotechnology Research, Innovation and Commercialisation in India prepared under ISTIP project (CSIR-NISTADS) by Sujit Bhattacharya (Principal Author), Shilpa, Preeti and Umang Gupta.

References

Bhattacharya, S., Jayanthi. A.P. Shilpa, Bhati, M. (2012). Knowledge Creation and Innovation in an Emerging Technology: Contemporary and Future Scenario in Nanotechnology". *Report prepared by CSIR-NISTADS for DST-NSTMIS*. (available at http://www.nistads.res.in/ under reports)

Coccia, M., Finardi, U., Margon, D (2012) Current trends in nanotechnology research across worldwide geo-economic players. *The Journal of Technology Transfer* 37(5), 1-11.

Bhattacharya, S., Shilpa, Bhati, M. (2012). China and India: The Two New Players in the Nanotechnology Race. *Scientometrics*, 93(1): 59-87.

Bhattacharya, S., Shilpa, Preeti, Gupta, U. (2015). Nanotechnology Research, Innovation, Comercialisation in India: Contemporary Status. *ISTIP Policy Bulletin 12*. http://www.nistads.res.in/images/bulletin/istip_bulletin12.pdf

Project on Emerging Technologies (PEN). Consumer Products Inventory. An inventory of nanotechnology-based consumer products introduced on the market. http://www.nanotechproject.org/cpi/

Ramani, S.V. (2014) edited. Nanotechnology and Development: What's in it for Emerging Countries. Cambridge University Press: USA.

Genet, C., Errabi, K., Gauthier, C. (2012). Which Model of Technology Transfer for Nanotechnology? A Comparison with Biotech and Microelectronics**.** *Technovation*, 32 (3-4), 205-215.

Archibugi, D. and Pianta, M (1992). The technological specialization of advanced countries: A report to the EEC on international science and technology activities. Boston: Kluwer

Nelson, R. National Innovation Systems: A Comparative Analysis. *Oxford University Press*, USA

Dosi, G. (1999) Innovation, Organization and Economic Dynamics: Selected Essays. Edward Elger

Lundwall (1992) National Innovation Systems: Towards a theory of innovation and innovation learning. Anthem Press. Anthem Other Canon Series.

Gerschenkron, A. (1962). Economic Backwardness in Historical Perspective: A Book of Essays. Harvard University Press.

Verspagen, B. (1992). Growth Rate Differentials between Uneven Economies PhD Thesis file:///C:/Users/admin/Downloads/thesisBV.pdf

Varblane, U. and Tamm, D. (2012). The development of the systemic approach to innovation In: Innovation Systems in Small Catching-Up Economies (Ed. Elias G. Carayannis, Urmas Vablane and Tonu Roolaht) pp. 3-20, Springer: London.

Huggins, R. and Izushi, H. (2007). Competing for Knowledge: Creating, Connecting, and Growing. Routledge: London and New York.

Cohen, Wesley, M. & Levinthal, Daniel A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly, Special Issue: Technology, Organizations, and Innovation*, 35 (1), pp. 128-152.

OECD (2010). The Impacts of Nanotechnology Companies Insights from Case Studies OECD Publishing.

Walsh, et. al. (2002). Differentiation Markets Strategies for Disruptive Technologies. *IEEE Trans. Engineer Management*, 49, pp. 341-351.

Ganguli, P. (2013). Best Practices on Commercialisation of Nanotechnology R&D Results. *In Manual on Critical Issues in Nanotechnology R&D Management an Asia-Pacific Perspective*. Prepared for Asian and Pacific Centre for Transfer of Technology of the United Nations – Economic and Social Commission for Asia and the Pacific (UNESCAP).

Rafols, I., Zwanenberg, P. V., Morgan, M., Nightingale, P., Smith, A. (2011). Missing links in nanomaterials governance: bringing industrial dynamics and downstream policies into view. *The Journal of Technology Transfer*, 36 (6), 624-639.

Koen, B and Bhattacharya, S. (2013). Emerging technologies in India: Developments, debates and silences about nanotechnology. *Science and Public Policy*, 40(5), 628-643.

Jayanthi, Koen, B, Bhattacharya, S. (2012). Nanotechnology: Risk Governance in India. *Economic and Political Weekly*, 47(4).

European Commission Second Regulatory Review in Nanomaterials (2012) http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52012DC0572

Robinson, D. K. R., Huang, L., Guo, Y., Porter, A. L. (2013). Forecasting Innovation Pathway (FIP) for New & Emerging Science & Technologies. *Technological Forecasting & Social Change*, 80 (2), 267-285.