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A conceptual framework to assess national capability to respond to NT developments

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Introduction

The importance of science and technology (S&T) in economic growth and social development is well understood. But the process of building S&T capabilities, which enables countries to engage successfully in scientific research and harness its benefits towards economic growth and development, requires further investigation. A grounded understanding of S&T capabilities for development purposes assumes greater significance in the context of developing countries that are engaged in 'catching-up' or 'leapfrogging'. This may enable developing economies to compete effectively in an increasingly globalized marketplace and overcome their relative underdevelopment. However, development of such capabilities is a challenge in such countries as there is always a continual emergence of new S&T developments. It is pertinent in this context to gain insights into the process of capability building and understand the capability requirements in the context of an emerging technology, such as in this case, nanotechnology.

This paper has the following objectives:

- To understand national capability through a review of the literature on S & T capability building.
- To assess NT developments in the context of developing countries and identify the key findings emerging from the research work under the project.
- To examine the drivers and dimensions of S & T capability and
- To assess how findings from the project research work would feed into the capability framework to successfully engage with this emergent technology.

Understanding S & T capability

The dictionary meaning of capability is the "ability to or skill to do something"[1]. With respect to S&T, capability could be explained in terms of an S&T system having the attributes needed for performance or accomplishment encompassing the depth and breadth of science and technological areas. It would denote the ability to harness S&T for production of commercial innovations that also have a societal relevance.

To harness the benefits of new technologies requires a minimum of S&T capability in choosing, acquiring, generating and applying technologies. Technological capability building

[1] Collins Essential English Dictionary 2nd Edition 2006

has been the focus of interest for more than two decades and the concept has evolved over years. (Bell 1984, Dahlman and Westphal 1982, Katz 1987, Lall 1987, Scott-Kemmis and Bell 1985). Westphal et al. (1985) defined technological capabilities as the 'the ability to make effective use of technological knowledge .... It inheres not in the knowledge that is possessed but in the use of that knowledge and the proficiency of its use in production, investment and innovation'.

The concept of technological capabilities emerged in the context of maintaining competitiveness in a changing environment. Bell and Pavitt (1995) referred to technological capabilities as the 'domestic capabilities to generate and manage change in technologies used in production, and these capabilities are based largely on specialized resources......need to be accumulated through deliberate investment – a management problem'.

However, capability approaches that focused solely on the aspect of generation of knowledge had some generic problems associated with them. Emphasizing only the knowledge generation aspect may not yield the desired result expected out of an S&T activity. A greater need to link knowledge generation to production of socially desirable outcomes was felt by policy planners and those engaged in S&T activities. Kim (1997) emphasized the process of creation of knowledge at the international level by focusing on firms in emerging economies. According to him, technological capabilities is 'the ability to make effective use of technological knowledge to assimilate, use, adapt, and change existing technologies. It also enables one to create new technologies and to develop new products and processes in response to the changing environment'.

Enos (1991) put forward a macro perspective of the concept and practice of technology capability. According to him there are three fundamental components of technology capability viz., individuals embodying skills, training, and experience and inclination; institutions within which individuals are assembled; and a "common purpose" defined in terms of objectives and motivations. Further, technology capability can vary between sectors and at various levels of aggregation – micro, sectoral, and macro. For example, in the industrial sector, the elements of technological capability – production engineering, manufacture of capital goods, and R&D are different from those essential for the services sector (Dahlman and Westphal, 1981). In general, the factors determining/influencing technological capabilities in developing countries are: adequate number and quality of human resources with practical experiences, skills, and aptitude; useful technological information on sources and conditions of technology transfer; institutions for education and training, for research and development, and for engineering design and consultancy; favourable natural environment and factor endowments, attitudes and customs, etc. (Fransman, 1984).

One of the major concerns in the science and technology debate is how to integrate scientific resources with the rest of the economy and what are the competencies and institutions that are required to put the knowledge that is being generated into effective use (Hall 2002, Chataway et al. 2005). Since its conceptualization, technological capabilities have taken into account the aspect of generation of technological knowledge and its organizational dimension i.e., the use of stock of technological knowledge. Contemporary literature emphasizes the role of institutions as central to building capabilities for production of knowledge and its effective utilization (Edquist 1997, Oyelaran-Oyeyinka 2005). The role of institutions - understood as norms, habits and rules – in determining the way people relate to each other, their learning behaviour and the ability to utilize the knowledge had been insisted upon by Johnson (1988). This is important from capability perspective in terms of determining the rate and direction of innovative activities. In this regard, capabilities can be best understood with respect to the contextual settings in terms of the institutions and its role in effective deployment of S&T resources.

The concept of capabilities of countries and firms to innovate has evolved over years. In the process it has gained a lot from the evolutionary economics literature (Nelson and Winter 1982). The various ideas on capabilities have found coherence in the concept of innovation systems, which looks at innovation - viewed conventionally as a linear process driven by research - in a systematic, interactive and evolutionary way, whereby networks of organizations, together with institutions and policies that affect their innovative behaviour and performance, bring new products and process into economic and social use (Freeman 1987, Lundvall 1992, Edquist 1997).

Adopting such a systemic approach of innovation as a network of institutions may help in identifying strategic needs and weaknesses and would thus be of importance from the perspective of building capabilities. One limitation of the systems of innovation approach is that it tends to be quite abstract and skeletal, providing a conceptual approach to understanding how organizations and institutions involved in R&D, product development and marketing relate to each other (Chataway et al. 2005).

Lall (1992), while linking technological capabilities and innovations has emphasized the role of national technological capabilities. According to Lall (2000), 'national technological capability is ... more than the sum of capabilities of individual firms in a country. It is an innovation system, which includes the externalities and synergies generated by the learning process, ways of doing business, and the knowledge and skills residing in related institutions'. The acquisition, nature and development of national technological capability is affected by intervention by government in providing a suitable incentive regime, particularly trade policies and domestic industrial policies. Also, government plays an important role in skills generation, availability of finance for technological activities and access to information all of which constitutes the factor market. Further, government intervention in terms of institutions supporting industrial technology such as, education and training, standards, metrology, technical extension, R&D among others) influences national technological capabilities.

There are reports (Royal Society 2004) highlighting the importance of science and technology and capacity building. Also, the issue of weak science and technology base of the South and its weak integration with the production has been dealt upon in detail earlier (Bell and Pavitt 1993, Garrett and Granqvist 1998, Ernst et al. 1998, Forbes and Wield 2002, Lall 1990). Developing economies, according to Brahmakulam and Wong (2002), have limited S&T capability and have weak and fragmented capacity for innovation. This hinders widespread application of new knowledge and its potential to bring about economic growth. According to them, there are many barriers affecting S&T capability on a sustainable basis in developing countries such as, shortage of human and institutional capacity, unfavourable economic policies restricting competition, lack of political will to implement reforms, maintain stable policies, enforce laws and pursue good governance. In lieu of the scarce resources availability and competing demand for finite resources they have suggested that for sustained capability building governments must adopt a long-term vision for making public investment decisions.

Sagasti (2004) opines that building science and technological capabilities is a Sisyphean task and the rapid evolution of frontier scientific research and technological innovation erodes and vanishes the hard won achievements – even makes insignificant - in building science, technology and innovation capabilities. According to him, faulty adoption of policies and decision-making by policy makers and politicians has destroyed research and innovation capabilities built over years in developing countries. He emphasizes the importance of mobilization of knowledge and innovation for development and argues that developing countries should pursue capability building for the creation, acquisition and utilization of knowledge through judicious investment of scarce resources. This should be done without ignoring the heritage of indigenous knowledge and techniques. Comparing the developed and developing economies on the capability front, Sagasti explains that the close and continuous interaction between science, technology and production led to the creation of an endogenous scientific and technological base in the developed countries. This enabled them to modify, adapt and recombine existing knowledge, which could be then deployed to produce goods and services. Through learning-by-doing and learning-by-using, the utilization of knowledge and technologies in the productive sector leads to incremental technical innovations. This also leads to accumulation of technological capabilities in the productive sector and to new areas for scientific research. Developing countries on the other hand were not successful in their endeavour to establish an endogenous science and technology base. In these countries an exogenous science and technological base was developed, which reflected few interactions between modern science, technology and productive systems with that of indigenous and traditional counterparts.

Despite the growing literature on capabilities the concept has not been dealt with in a sufficiently integrated way. Not much attempt has been made to link science, technology and institutional innovative capabilities with social development (Pettit and Wheeler 2005). Further, the literature on S&T capabilities has also not focused much on how societal context on one hand shapes technological innovation and on the other how it influences the ability to find solution. In this regard, a deeper understanding of local capability, need, and market becomes important. Fabayo (1996) has stressed the need to adapt capability building to specific needs and goals of different countries and regions. This paper while developing a capability framework for emerging technologies in the context of LDCs views capability as a multidimensional concept and attempts to draw together the various segregated perspectives on capabilities so as to gain a wider and holistic understanding.

In this regard, building capabilities has to be viewed as a continuum across the entire chain of knowledge generation, utilization and commercialization. There could be various approaches to building capability in the chain, for example, investments in research and scientific capability, investments in non-scientific skills, creation of enabling environment for the generation and application of knowledge, development of linkages, strengthening the policy process, strengthening stakeholder engagement and bringing about institutional changes.

Why is a national capability in S & T important?

Capability in S&T holds special significance as it enables countries to produce and innovate rather than becoming a mere user of goods and services. It is well established that if developing economies could effectively harness a portion of the technologies presently available globally, they can rise in the ladder of socio-economic development. However, technologies need considerable effort to access, master, adapt and use efficiently. This calls for a conscious effort to build capabilities.

Also, capability in S&T would enable countries to address their developmental needs such as developing low cost technologies in areas like sanitation, healthcare, energy, nutrition, elementary education and housing. Although several advanced technological options in the above mentioned areas might already exist, however, they must be customized to local conditions. To undertake such a task would require the existence of a certain degree of capability.

Furthermore, with trade liberalization and rapid technical changes, developing countries want to have access to new technologies to compete in world markets. However, new technologies may require higher skills and involve technical and organizational demands. This may pose a challenge to developing economies in engaging with these technologies and deriving benefit from it. This underscores the importance of developing capability. Moreover, it has been observed that within the developing world, countries that have effective capability building processes are able to perform better than those that have not (UNIDO 2002). This also explains that building capabilities is a continuous and cumulative process and countries have different level of capability.

In what follows, we examine the kinds of demands created by an emergent technology, such as nanotechnology, on the S & T system of a developing country.

Nanotechnology and its application potential in developing countries

Nanotechnology refers to the development and application of materials, devices and systems with fundamentally new properties and functions because of their structures in the range of about 1 to 100 nanometres (Siegel et al., 1999). It involves the manipulation and/or creation of matter at the nanoscale at which the characteristics of the matter changes significantly because of properties such as the dominance of quantum effects, confinement effects, molecular recognition, and an increase in relative surface area (Renn & Rocco 2006). Some materials and processes in nature are also this small. However, what makes nanotechnology different is that it is based on the recent ability of humans to consciously engineer materials and machines at the tiny scale of 100 nm or less. In addition to size, nanotechnology is also exciting because many nanomaterials have new, never seen before properties. Downsized material structures of the same chemical elements change their mechanical, optical, magnetic and electronic properties, as well as chemical reactivity leading to surprising and unpredicted, or unpredictable, effects (ibid.). Thus, an existing material, on a nanoscale, can be transformed to have different properties, opening new technological possibilities.

S&T capabilities: key for engaging with nanotechnology

To realize the actual application potential of nanotechnology would depend on capability at the national level to engage successfully in the emerging domains of science and technology. This would pertain to the ability of existing S&T institutions to engage with such technologies; industrial competence in undertaking the task of technology selection, classification, adaptation, exploration; availability of financing; a proper understanding of the market structure and function; ability to design and implement S&T policies; ability to address challenges to convert research into technology and development of suitable legislative and regulatory framework for such technology.

Although the above-mentioned capability requirements are generic and are significant for any emerging technology, however the nature and characteristics of nanotechnology offers some distinctive challenges. Nano S&T research work has to be carried out in an interdisciplinary fashion and the nature of technology is quite complex. Because of it's highly multi-disciplinary nature cross cutting many industries and technology chain, nanotechnology reshape the existing organizational arrangements amongst actors giving rise to new forms of configurations. These pose a significant challenge to the existing S&T system of a country in engaging with such technologies.

Furthermore, nanotechnology besides offering a wide range of opportunities for development also raises several ethical and social issues pertaining to risks and accessibility. Therefore, the trajectory of nanotechnology development, if left to the forces of commerce and competition, the most important questions about nanotechnology pertaining to hazards and risks to human health and the environment may not be posed sufficiently. It may so happen that the benefits are stressed and questions skewed towards issues of sufficiency of investment, profitability, receptivity of markets, intellectual property, speed of innovation and application (Mehta 2002). Therefore, extending the discourse to include human welfare issues would be important.

In the above context, the process of developing capability with respect to nanotechnology may require reorientation of dimensions characterizing capability. Therefore, it would be important to gain an understanding of the existing S & T capability, and how it needs to evolve to engage with nanotechnology.

Key findings from other project reports of the study

The following emerge as key findings from the *Review of international nanotechnology developments and policy concerns* that developing country wanting to develop nanotechnology need to address:

- Globally the R&D scene in nanotechnology is very dynamic. However, there are limitations to converting these development into products due to issues like, increasing the scale of production of nanomaterials while ensuring satisfactory quality and affordability, ensuring nanomaterials availability having desirable characteristics, engineering and adapting the nano-based system to specific local needs and goals, and addressing the environment, health and safety concerns in the use and disposal of nano products.
- The R&D focus in nanotechnology globally is diverse with countries developing technologies in areas responding to their own expertise and needs. This calls for development of clear national strategies to engage with nanotechnology.
- Nanotechnology has many applications in the energy sector and holds lot of potential to contribute significantly towards solving some energy and environment concerns. Clean and advanced energy technologies in combination with energy efficiency and energy diversification are critical for LDCs to improve access to energy. Research on nanotechnology related to energy and environment applications are primarily driven by the need to overcome limitations of existing technology, improving efficiency of processes, reducing

size and cost of products and, opening up new applications and markets.

- Government has played a predominant role in the research effort in terms of funding, establishing the scientific and technological infrastructure and developing human skills and capacity. However, the role of agencies in supporting research should be guided by the sectoral dynamics in terms of state of research infrastructure and technological level of production.
- There is a greater focus on industry-academia partnerships for transformation of fundamental discoveries in nanotechnology into products.
- The demand of trained personnel in nanotechnology is expected to grow and there is a considerate need for development of human resources having an interdisciplinary orientation for rapid progress of nanotechnology.
- Societal needs may differ between developed and developing countries. Accordingly there is a need to link nanotechnology development with specific needs and goals of the society.

The following key issues emerged from the research work on *Understanding multi-dimensional risk of nanomaterials and products on environment, health, and socio-economic domains*, and *Regulatory framework in place in India*:

- Giving adequate priority to risk research in nanotechnology. Research on issues related to environmental, health and safety (EHS) aspects of nanomaterials is important.
- Need for early and advanced risk assessment studies in nanotechnology research. Socio-economic risk assessment is yet to evolve as a component of scientific risk assessment, especially in the context of developing countries.
- Need for detailed risk research encompassing nature, extent of toxicity and levels of accumulation and deposition caused by them.
- Standardisation of toxicity tests of nanomaterials so as to avoid duplication of results in laboratories and expert controversies.
- Contextualizing the economic risks that nanotechnology would pose and forging linkages between the arenas of trade policy, industrial policy, labour policy and social policy. The prospect of technology displacement due to nanotechnology applications would have to be met with a host of well-coordinated measures such as compensation for livelihood losses, flexible trade and

employment policies, as well as exploring trade diversification options.

- The patent regime can also significantly affect availability of technologies. A restrictive patent regime can have an adverse impact on a countries capacity to benefit from an emergent technology.
- Bridging the trust deficit existing between the optimism of scientific community and the apprehensions expressed by public interest groups regarding the potential of nanotechnology. Drawing a balance between enhanced public awareness and scientific expectations.
- Stakeholder engagement in the technology development and implementation process. Information provided needs to be tailored to the knowledge level of different stakeholders.
- Government should take an early lead in involving civil society in the deliberations over a future framework for nanotechnology governance, specifically the risk assessment, managements and mitigation framework.
- Need to put in place adequate structures to carry out risk assessment procedures and ensure laws and policies that would address the liability and redress issues inherent in the application of nanotechnology having unknown environmental and health impacts.
- There is a need to rationalise the present legislative structure in order to be made applicable to nanotechnology.

Research findings from the work done until now under the project thus indicate that to successfully engage with nanotechnology, developing countries would need to address a range of issues pertaining to research, technology development, skills requirement, institutions involved, risks issues, regulatory and governance structure and stakeholder engagement.

Building S & T Capability

Drivers and Dimensions

Building S&T capabilities has to be viewed as a continuum across the entire chain of knowledge generation, utilization and commercialization. Looking at the actors and the institutional context in which knowledge generation, utilization and commercialization takes place, the S&T system includes universities and research organizations, private firms - multinational and national, small and medium enterprises, industry associations, policy making bodies, entrepreneurs, non-governmental organizations, supportive structures such as markets and credit, and regulatory infrastructure.

For research to contribute to economic growth, the existence of knowledge base in terms of critical mass of trained scientific manpower in various areas of S&T having ability to create, adopt and apply knowledge is necessary. Investment in research, education and industry becomes important from this perspective.

Firms can benefit from the existing research and knowledge base and increase their productivity and income. In order to achieve this, firms would have to undertake the task of **adoption** of research results and utilize it in their production process to **develop** technology products. Subsequently, **demonstration** and **deployment** of the developed technological products and its successful **commercial launch** in the market will have to follow. Various factors like policies, human resources, infrastructure, market conditions, business practices would influence the performance of these activities.

Market plays an influential role in shaping the trajectory of technology development. The presence of an efficient factor market leading to competitive capabilities, the labour market providing the new skills needed, the financial market providing the capital to finance learning, and the technology market providing the information needed to master a new technology (Lall 2006), becomes important from the perspective of building capabilities. Any capability building exercise should satisfy the end result of socio-economic development. For this the technology products being created needs to be taken to the market for user adoption. Users adoption of knowledge and tools would be influenced by market demand, cultural preferences, and access to finance among others (Brahmakulam and Wong 2002). In this regard, it is important to distinguish that putting products on shelves i.e., deployment is different from its market acceptance. This suggests the importance of market reforms for adoption of a new technology by users (ibid.).

In Figure 1.1, the linkages between various components denote that the traditional linear understanding of knowledge transfer from basic research to production and commercialization have been replaced by non-linear models of innovation flow composed of several actors and interactive learning. The feedback loop underscores that S&T development is a dynamic process and it is important that research and innovation activities are relevant to the market. In this regard, the framework for S&T capability has to be viewed both as a system and process. It is a system since the existence of inter-linkages and knowledge flow among the heterogeneous set of elements would be crucial. Further, building S&T capability is a continuous process as there are always opportunities and demands on the anvil, thus requiring a constant redefinition of strategies and policies on the part of various actors to engage with them.

The four poles of **knowledge**, **technology, regulation** and **market** drive the process of S & T capability building. The knowledge pole embodies the research and knowledge base which determines the pace and direction of S&T within a national boundary. The competence level in the existing knowledge domains can act as a stimulus for engaging with emerging technologies. The technical pole characterized by the ability to produce new goods and services also impinges upon the innovation process. The degree of penetration in existing technological fields and the breadth of technical areas covered would enable countries to venture into emerging technologies. The technology level of industry and technological level of production would characterize this. The third driving force is the market pole, which relates to demands of goods and services by users and customers. The regulatory pole includes legislations and secondary rules and also includes government policies. However, it is important to make the caveat that in one sense the regulatory pole would underline all the other poles in as much as separate sets of laws and regulations would be operational to enable the functioning of each of the other poles. Thus it is important to delimit the ambit of this pole. The subject area of the regulatory pole largely relates to environmental, health and safety, production and marketing, consumer protection, producer responsibility and product quality and waste disposal laws and regulations. The pole will also include institutions an important part of the structural framework enabling the implementation and functioning of the legal regime.

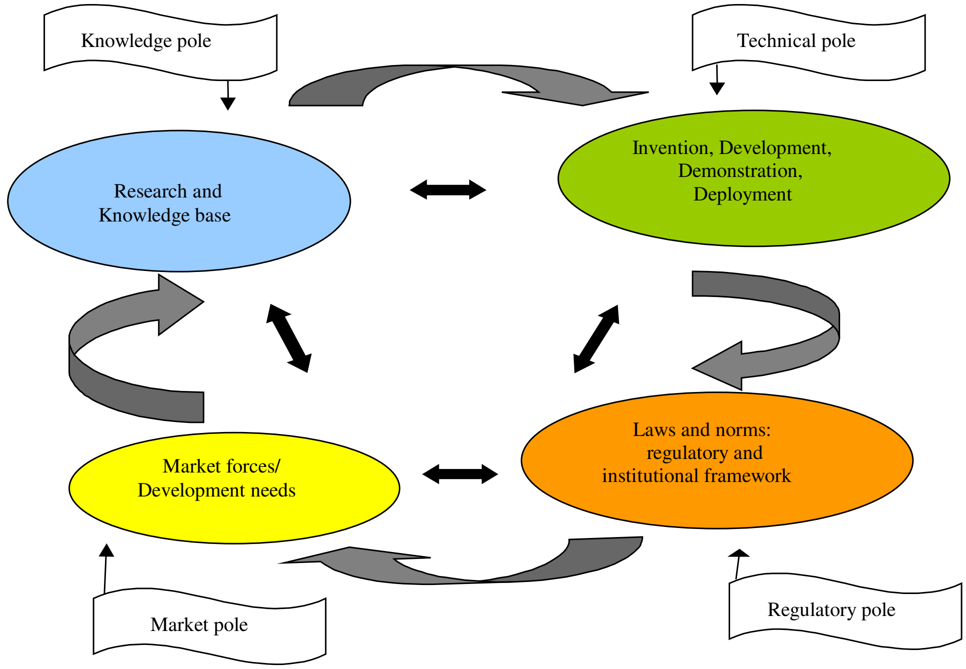

Figure 1.1: The interactive S&T base of drivers, systems and responses

S&T capability can have different dimensions: Existence of robust scientific organizations such as universities, public and private research institutes signifies **organizational** capability. Innovative firms for effective utilization of the knowledge being generated in scientific and research institutions furthering the process of technology development connote **enterprise** capability. Technically and scientifically skilled workforce constitutes the **human resource** capability. Capability relating to formulation and implementation of effective S&T **policies** holds an overarching significance by encouraging stable investment in human and institutional resources to adopt, adapt, apply and develop new ideas and technology and maximize their effect on economic development. Policy also has an important role in facilitating linkages between organizations, improving information flow and exchange between private and public sectors and strengthening institutions that facilitate innovation. Another important dimension of capability is the sufficient and timely availability of **financial** resources to support S&T. Last but not the least, the existence of **social institutions**, which actively respond to S&T developments, constitute an important dimension of S&T capability.

Capability dimensions and their characterization in the context of nanotechnology

R&D

The process of building S&T capabilities requires the existence of robust scientific organizations – universities, public and private research institutions - wherein knowledge, having potential for technological innovation is being generated. Production of knowledge in universities and research institutions via R&D is an important dimension determining capabilities. Also, the academic system is the major source of human resources development in S&T.

Nanotechnology has been accorded national R&D priority in both developed and developing economies. This is evident from rapidly increasing government investment in R&D in this area. Given its vast application potential in diverse areas, for e.g., health, energy and environment, agriculture, materials etc., nanotechnology forms an important part of national science and technology agendas in these sectors. At the international level the thematic areas of nanomaterials, nanoelectronics, nanobiotechnology, nanoanalytics and nanophotonics are of considerable important with regard to nanotechnology R&D.

Although the national R&D strategies of countries may vary, some key trends could be deciphered globally. This may be important from the perspective of building capabilities in developing economies.

The requirement of nanocentres has been acknowledged globally and as a result specialized centres in the field have started to spring up. This is mostly to harness the potential of the emerging discipline of nanotechnology and to effectively address issues of risk, establishment of best practices and standards. The present focus is on widening the knowledge base and of monitoring development so as to devise effective strategies in the future.

International networks are emerging as the locus of innovation in the international nanotechnology landscape. Also, there is an increasing trend of partnerships involving public sector research institutes, private sector and the government. Specialized research centers in nanotechnology are being established by leading countries in nanotechnology serving as incubators for innovation. Further, there is a focus on development of instrumentation and standards globally to successfully harness the potentials of this emerging technology.

Young and highly dynamic fields of S&T such as, nano science and technology, which are interdisciplinary in nature, would require S&T organizations to work in an interdisciplinary mode. Many research breakthroughs in nanotechnology are stimulated in the intersection of established scientific disciplines and across fundamental and applied technological research. For instance, consider that organizational infrastructure dedicated to the fundamental understanding of certain nano-scale properties (basic research) is institutionally separated from the organizational infrastructure for modifying nano-scale phenomenon (applied technological research). Therefore, inter-institutional collaboration, combining scientific knowledge from various disciplines in universities and laboratories, is an important dimension of performance in the emerging field of nanotechnology. This may pose quite a challenge to traditional institutions and the preparedness and the ability of S&T organizations to overcome these would greatly determine its capability to tap nanotechnology. Further, the ability to tap global knowledge base by forging international partnerships can go a long way in effectively harnessing this technology in the context of developing economies.

For developing organizational capability in nanotechnology, establishing new multi-disciplinary research centres in nanotechnology, starting centers of excellence in existing S&T institutions and national consortia on R&D in nanotechnology, consisting of different nanotechnology R&D institutions could be advantageous.

As discussed earlier, nanotechnology may pose significant risks to human health and environment. Therefore, developing research capabilities in risks and safety aspects would be key to ensure that human welfare discourse is taken into account in the quest for harnessing nanotechnology.

Since, technologies are socially embedded, understanding the socio-economic implication of any technological intervention is important. Its importance in the context of emergent technologies assumes greater significance in deciphering the ethical, legal and social implications of such technologies. This calls for developing social science research capability to undertake research in such areas.

Technology development

Tracking international nanotechnology developments it could be observed that there is a strong focus on the commercialization of advancements already made in R&D. Further, there is a growing interest of various economic enterprises in nanotechnology. As nanotechnology have cross sectoral applications, firms depending on their capability are making decisions regarding whether to focus on one technology or market structure or cross boundaries between different nano-scale technologies.

Firm level case studies in the UK (Chillcott et al. 2001, Meyer & Morlacchi 2003, cited in Meyer 2006) and Germany (Tisnado 2005, Meyer 2001, cited in Meyer 2006) have shown that firms rarely cross boundaries between different nanoscale technologies such as, nanoparticles, nanostructured films, or nanocomposites.

Further, looking at the way firms and industry dynamics are unfolding in nanotechnology, Palmberg & Nikulainen (2006) have observed that there are a large number of start-ups, which have sprung up in this field besides the existing firms who have tried to incorporate nanotechnology in their production processes. They indicated that ‘top-down’ nanoscale engineering approaches are more likely to enhance the capabilities and knowledge base of incumbent firms. As such, large established firms in end product industries (chemicals, electronics, forest based and metal industries) would be able to harness nanotechnology. However, for an incumbent firm to make transition from an old technology to a new technology would be determined by the characteristics of the new technology such as its complexity and socio-economic benefit, capital intensiveness (it can be supplied by small firms), radical nature so as to inhibit investment by large firms concentrated on existing technologies among others. On the other hand, ‘bottom up’ nanoscale engineering approaches might favour new entrants over large incumbents.

Nanoscience and developments in nanotechnology are expensive and require cooperation between industry and research institutions. Industry-academia interaction in nanotechnology appears to be of great significance due to the need to translate nanotechnology research into products and services having market potential. To enhance academia – industry interaction in nanotechnology several strategies have been adopted, for e.g., tax incentives, financial support for small business and start-ups, formation of networks in nanotechnology and funding of collaborative projects. Japan is promoting successful industrialization of nanotechnology through projects aiming at enhancing technology transfer from academia to industry and providing incentives, such as prioritizing research funds, for effective collaboration between industry, academia and government.

Since nanotechnology has cross sectoral applications, firms will have to undertake strategic decisions whether to (Meyer 2006)–

- occupy a technological niche and apply their proprietary technology to one specific application area
- build on a base in several nanotechnology areas and by integrating technology and expertise in more than one nanotechnology area develop solutions for one are of application,
- pursue an approach that champions customizing expertise and technology to a range of different application areas, or
- combine expertise in more than one nanotechnology with more than one application area

Further, nanotechnology being expensive and complex would require greater collaboration between industry and academia. Ahluwalia (1994) refers to such projects as "megascience." Megascience projects are defined as those undertaken primarily for the production of knowledge. They require formal management structures and resources that cannot be provided by a single agency, firm, or perhaps even country (for example the Human Genome Project). The emergence of new science-based innovations has renewed concerns about how megascience projects are funded and how innovations from them get diffused. There are three main types of industry-university relationships (Etzkowitz and Webster 1995)

short-term: (i) consultancy and research by individual professors; (ii) industrial procurement of services – education and training, testing, targeted contract research: problem solving, non-targeted technology transfers – diffusion oriented, patents;

medium-term: (i) corporate contributions – fellowships, targeted contract research: design and engineering, development, applied research, non-targeted contract research: pre-competitive research; (ii) co-operative research – joint research programmes, R&D consortia, joint R&D laboratories;

long-term: (i) privately funded research centres – multicorporate, single funder; (ii) long-term research contracts: basic, fundamental pre-competitive research; (iii) university-controlled companies to exploit research, private companies that secure patent rights for resale

However, the flow of knowledge from research institutions to an industry is not an easy matter. In developing countries there is not much interaction between industry and academia. This would pose a significant challenge to the developing countries in its ability to harness the benefits of nanotechnology. In this regard, the transition of academic knowledge into commercial sector would require several factors, such as excellent research results, managerial & industrial competence and financial support among others.

Also, the ability of a firm to produce new or improved products, processes and services is dependent on other dimensions of capability like financial investment and human resources in R&D, and academia-industry linkages. The role of policies in shaping the firms learning behaviour becomes crucial. Policies on trade, competition and labour affect firms learning by means of the signals firm receives from the market (Lall 2006). Also, institutional factors such as, the intellectual property rights (IPR) regime has a great influence on the choice of innovation in firms, which have to make decisions pertaining to - whether to go for indigenous R&D or, source technology from outside. At the same time, business practices and social capital gains importance by way of affecting firms interaction pattern with each other and the way they respond to government policies (ibid.). Thus, enterprise capability has to be viewed in relation to its linkages and dependence with other dimensions of S&T capability.

Financing

Sufficient and timely availability of funding to support developments in S&T is another very important dimension of capability. Funding is required across the innovation chain starting from knowledge generation, utilization and commercialization. Looking at the global scenario in nanotechnology funding, countries have used different mechanisms to coordinate R&D activities at the national level. For example, France, UK, and USA have a central coordinating body with funding mechanisms specific for nanotechnology. While Canada, China, Ireland, Italy and Japan provide funding through existing national funding and research mechanisms under a consultative body in the government, Germany and South Korea provide funding through individual ministries and agencies.

As R&D is highly risk and capital intensive activity, existence of a suitable financing mechanism could be a key factor for the growth of industrial R&D. Availability of early stage investment capital would be an important factor that will determine the commercialization of R&D. Internationally, venture capital funds provide seed capital for start-ups, and new R&D projects are funded by special purpose vehicles (EXIM Bank of India

2006). However, in developing countries such mechanisms are either non-existent or, are at a very nascent stage. In order to engage with emerging technology would require support from public funds, venture capital, special investment funds, multilateral, bilateral support funding. For transformation of research outputs of S&T organizations in nanotechnology into commercial ventures, there is a need to encourage venture capitalists in forming partnerships with R&D labs.

Human resources

Developing human resources capability is an important dimension of capability building process for advancing innovation activities and generating productivity. For technology intensive R&D, availability of qualified researchers, scientists and engineers is very important.

Emerging technology requires constantly upgraded skills and competencies across the entire innovation chain, starting from performing R&D in the lab to working at the firm level. An interdisciplinary oriented workforce capable of working in the area of nanotechnology would be necessary. In this regard, imparting education in nanotechnology at undergraduate, post-graduate and higher levels could be a step forward. Providing training to the scientific staff in this emerging technology could be another step, which could be undertaken. However, there is a need for change in the manner in which scientists are trained in the frontier science and technology areas. Instead of confining the training to only the technical specificities, it should also involve imparting training in complementary skills like IPR, building partnerships among others. This would help in gaining a wider view of the work and in undertaking collaborative work.

Insufficient human resources in R&D - both in public and private sector research institutions - and their quality are a constraint, particularly in the settings of developing economies. In developing countries there has been a decline in the number of students opting for research in basic sciences. In the context of nanotechnology, which derives its strength from basic science research, such trends may pose considerable challenge. In this regard, generating academic interest in basic as well as applied sciences and providing financial support to attract and retain science and engineering student could be adopted towards building talented manpower.

Further, entrepreneurial capability acting, as a medium in the transfer of technology from the point of generation to the point of utilization is also an important element determining capabilities, especially when the rate of technological change is rapid.

Policy systems and process

Building S&T capability is a long and cumulative process (Juma and Konde, 2002) and besides scientific and research institutions and laboratories, stable investment in human and institutional resources to adopt, adapt, apply and develop new ideas and technology is required. In this regard, S&T policies are imperative to encourage such investment and maximize their effect on economic development.

Government has played a predominant role in the research effort in establishing the scientific and technological infrastructure. To effectively harness the potential applications of nanotechnology, countries around the world have devised strategies and undertaken policy initiatives. Inter-ministerial bodies have been established to provide guidance for policy development. In countries like the US, China, Japan, and South Korea there are interagency coordinating offices under the offices either of the prime minister or president. Further, policies on nanotechnology aimed at enhancing cooperation and partnerships between organizations, addressing challenges to convert research into technology by improving information flow and exchange between the private and public sectors have been undertaken in countries forerunners in nanotechnology in the world. Also, policies to facilitate innovation and technology diffusion by strengthening institutions have been devised by leading countries in nanotechnology in the world.

As nanotechnology has application potential in several sectors, each having different needs operating over divergent timescales and exposed to different market dynamics, countries have also developed or are in the process of developing sector specific strategies and policies.

In the context of developing countries the role of S&T policy, besides deciding the level of investments and prioritization of sectors, the level of importance attached in engaging with the ethical, legal and societal dimensions – all requiring a substantial amount of funding - would enable a smooth and healthy penetration of nanotechnology within a national boundary. Also a critical issue in the policy making process would be the development of capacity in the usage and maintenance of advanced products using cutting edge technologies, such as nanofilters, nano photovoltaic cells and the like. Given that nanotechnology has application potential in various sectors of the economy, development of cross–sectoral policies for nanotechnology may be a critical approach to the capability building process.

Societal interface

Science and technology are not independent variables and the interaction between science and society takes place within a particular socio-economic context. Question pertaining to when and how should societies make decisions about regulating, developing, investigating, and investing in technologies needs to be properly addressed to strengthen S&T capability.

Emerging technologies may need new regulatory approaches and legislative mechanisms because of its size, environmental spin-offs and its disposal. When current legislation proves insufficient there is a need for either specific legislation and regulations for nanotechnology or adapting existing legislations as per the demands posed by an emerging technology. To customize existing legislation, several countries have, as a first step, focused on developing appropriate monitoring and warning systems. However, there are some important caveats regarding changes in legislation. While designing regulatory policies, the changes being made should facilitate innovation rather than being restrictive. Also the period of regulatory uncertainty should not be too long.

In the context of nanotechnology the issue of risk is of prime importance. The small size and the new physical and chemical properties and functions of nanosystems may pose diverse risks resulting form their interaction with human and natural systems. The risks may have national as well as global repercussions in terms of economic imbalances and widespread environmental contamination. Studies on nanotechnology have indicated the lack of information about the human health and environmental implications of manufactured nanomaterials and issues of safety concerns pertaining to emerging technologies have been raised (Michelson 2004)

Accordingly the area of risk governance in nanotechnology becomes significant. Risk governance includes the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken (Renn and Roco 2006). Risk governance is an important concept for assessing and managing the implications of nanotechnology in the context of relationship between new technologies, risk and sustainability (ETC Group 2003, Burke 2003). Renn and Roco have identified the deficits of the risk governance system for different nanotechnology generations. Low level of knowledge of the new properties and functions on toxicity and bioaccumulation, limited understanding of the nanomaterials exposure rates, and gaps in the regulatory systems at the national and global levels are the main deficits of risk governance for the first generation of passive nanostructure (nanoparticles, coatings, nanostructured materials). While for the 2nd, 3rd and 4th generations of nanoproducts (including active nanodevices, nano-bio applications, and nanosystems) the main deficits include, uncertain/unknown evolution of the technology and human effects as well as a framework through which organizations and policies can address such uncertainties.

Although several projects addressing environmental, health and safety (EHS), (including toxicology, workers safety, and ecotoxicology, as well as standards, nomenclature and patenting), have been initiated in different countries around the world in the last few years however, the area of risk governance has not been given adequate attention.

Given the importance of risk research in nanotechnology developing countries having limited resources have to prioritize between funding research for commercialization and risk research. Although the nature of risk would be similar for nations engaged in the pursuit of nanotechnology development, the extent of exposure of these risks to populations would be largely determined by the institutional capacity of countries indicated by dimensions, such as, existing regulatory mechanisms, communication policy, stakeholder participation in establishing and reviewing safety standards and the like. Developing economies in order to engage with nanotechnology should enhance capabilities on the above dimensions pertaining to risk governance and urgently address the gaps in research and policy making in the area.

Stakeholder engagement

Multi stakeholder interaction in S&T, involving civil society & community organizations and media among others, becomes crucial from the standpoint of efficient technology development and deployment, responsible and sustainable technology development and greater commercialization success. However, to successfully do so would require responsiveness and flexibility on the part of the S&T organizations, enterprises and policy makers towards these issues.

Social institutions like civil society organizations (CSOs) can play an important role in the alignment of research priorities to that of development needs of a country. With their field level experiences, CSOs can support scientific community in setting up of research priorities. A wider understanding of the policy dimensions, which are increasingly becoming complex in the wake of globalization and IPR developments, requires developing certain degree of capability in these areas. Some of the CSOs work actively on these policy areas and have developed international linkages, which helps them in gaining quick access to international developments and agreements. Therefore, CSOs can provide crucial inputs in policy making relating to the likely impact of international S&T developments on the domestic sector.

Further, CSOs can provide a better understanding of various policy developments including those related to IPRs in nanotechnology, as and when they emerge, and also on international developments related to framing of issues related to risks of nanotechnology.

Towards developing a conceptual framework to assess national capability to respond to nanotechnology developments

A conceptual framework to assess national capability to respond to nanotechnology development needs to address the key opportunities and challenges created by this technology for developing countries in terms of the demands imposed on the science and technology infrastructure and by changing the nature of science and technology. From our review of international developments in nanotechnology following observations can be made:

- there is a need for strong infrastructure to enable and stimulate R&D and commercialisation of nano products;
- constraints and concerns among users must be addressed for successful deployment of technology;
- appropriate strategies, policies and institutions are needed to engage with an emergent technology;
- human resources with multidisciplinary perspectives is key for progress in nanotechnology;
- there is a need for addressing nanotechnology risks in the societal context;
- regulatory oversight for nanotechnology is necessary to channelise research efforts in a specific direction;
- transparency and public involvement in the design and implementation of regulatory structure in nanotechnology should be ensured.

Developing capabilities in emerging technologies thus would require: a) skills of both scientific and non-scientific kind, b) a greater degree of linkages between various actors from academia, industry, policy makers would be necessary for successful market deployment of such technologies, c) the interdisciplinary approaches in nanotechnology would demand a different R&D strategy as well as reorientation of science and technology activities in universities, research institutes, funding agencies and industry with a conducive institutional setting facilitating interactive learning would be essential to respond to and develop nanotechnology, e) devising adaptive and responsive governance structures that can suitably regulate applications of nanotechnology in society, and e) a flexible, dynamic policy environment that has the ability to create the conditions required for both knowledge generation and its effective utilization would form an important dimension guiding the process of development of capabilities. See Figure 1.2

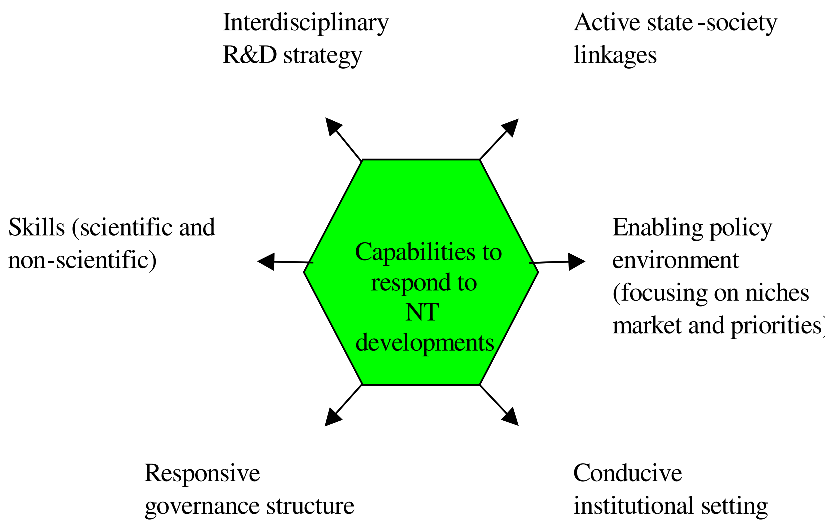

Figure 1.2: Capabilities to respond to nanotechnology developments

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