Bionetworks vs. nanonetworks: a comparison of diffusion rates of emerging technologies

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Abstract: This exploratory investigation offers evidence from biotechnology and nanotechnology sectors regarding the differential impacts of information flow rates, dispersion of networks and combination of progenitor sciences and technologies on technology diffusion rates. In recent years, enhanced rates of information flow have increased the ability for a greater overall number and diversity of foreign players to enter emerging technology development trajectories. At the same time, these trends are creating more dispersed networks with concomitant problems associated with information flow in such diffuse situations. Rates of diffusion of emerging technologies are also importantly affected by the number of scientific fields and generic technologies combined to create the new technology and the level of resultant complexity; higher levels of complexity can slow down diffusion rates. Further, at the country level, absorptive capacity is largely determined through institutions and their policies; however, in terms of enabling diffusion of technology to move effectively downstream from science to market, this requires social capabilities.

Keywords: networks; biotechnology; nanotechnology; national systems of innovation; diffusion of technology.

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1 Introduction

This exploratory investigation offers evidence regarding the differential impacts of

1 information flow rates
2 sectoral network centrality
3 complexity of combining progenitor technologies on technology diffusion rates, internationally.

The paper specifically focuses on India as an international case study. In recent years, enhanced rates of information flow and exchange, facilitated by the internet, higher levels of student and labour mobility, alliances, and the existence of global manufacturing facilities, have increased the ability for a greater overall number and diversity of international players to enter emerging technology development trajectories. At the same time, these trends are creating more dispersed, or in other words, less centralised sectoral R&D networks with the concomitant problems typically associated with information flow in such diffuse situations (i.e., lack of face-to-face knowledge transfer which is needed in the process of 'tacit knowledge' exchange). This problem is believed to be exacerbated even further in the case of emergent technologies, such as nanotechnology, which require the integration of multiple underlying sciences.

One known amplifier of the ability for networks to be effective at the country level may be public institutions which act in ways that have important impacts on innovation systems, both in terms of effective public policy and provision of resources (at the national, regional and sectoral levels). Additionally, foundations, VCs and NGOs may serve as centralised bodies for information and funding funnelling in the early stages of a country's adoption of a technology. Similarly, international networks and collaborations offer such funnelling of international information, talent and sometimes, capital. In other words, effective country-level public policy mechanisms which coordinate such efforts by institutions have the potential to serve as bullwhips by acting specifically to positively impact a given country's absorptive capacity (Cohen and Levinthal, 1990; Fagerberg et al., 2009) and thereby speed up diffusion beyond the rate that would be obtained in countries lacking in such efficient and effective mechanisms. As Abramovitz (1986) has suggested, developing countries only carry 'the potential for catching up', but that this opportunity may or may not materialise. Innovation systems theory (Freeman, 1984; Freeman and Lundvall, 1988; Lundvall, 1992; Nelson, 1988, 1993; Malerba, 2004) builds on Abramovitz and others who have pinpointed the critical role of institutions such as organisations, policy incentives and regulations affecting innovation diffusion in catching-up-countries, because they enable the absorption of existing science and technology to put their own spin on it. This line of thinking is drawn out further by Niosi et al. (2010) as they demonstrate in their eight-country study of developing economies that while many developing countries may have progressed in terms of their scientific diffusion of new technologies, those that have been most successful in terms of further downstream diffusion are those that have been able to leverage their social capital, either through collaboration, alliances, ability to attract VC, foreign talent or through their downstream marketing capabilities. In other words, whether countries are really able to take advantage of early scientific opportunities that diffuse to them depends on their amalgamated 'social capabilities'. Social capabilities are those values, skills and assets which enable access to social capital. Social capital relates to the value of social networks. While a multitude of definitions exist, Baker's (1990, p.619) definition sums up the general dynamic: "social capital is a resource that actors derive from specific social structures and then use to pursue their interests".

Initial evidence regarding the differential impact of the key factors (i.e., information flow rates, network centrality, integration of science bases and absorptive capacity) on international diffusion rates is offered in a comparison of two technology trajectories originating in the 20th century. Specifically, the generic emergent technologies of interest come from the fields of modern biotechnology and nanotechnology. These fields offer great insight as their diffusion has had enormous impact in terms of public policy, university funding, industry development and financing, stock market impact and new product development, and will both continue to do so into the foreseeable future.

Modern biotechnology refers to a set of generic technologies involving change of the genetic patrimony of living organisms for industrial application. A recent report by the OECD includes the following generic technologies: DNA/RNA techniques, gene and RNA vectors, proteins and molecules, tissue and cell culture/engineering, process biotechnology techniques, bioinformatics and nanobiotechnology (van Beuzekorn and Arundel, 2009).

'Nanoscience' refers to the study of the nanostructures and nanomechanics occupying the 0.1 to 100 nanometre space, whereas other definitions emphasise that nanotechnology focuses on the intentional manufacture of large-scale objects built from nano-scale components (Niosi and Reid, 2007). As such, all scientific disciplines which operate at this scale must contribute to nanoscience, meaning that nanotechnology is complex and involves the intentional integration of these sciences (i.e., molecular biology, electronics, materials science, physics and so on) in meaningful ways. Nanotechnology, therefore, does not refer to a single technique but to many different underlying pro-genitor scientific fields and technologies that enable manipulation of matter, such as measuring, designing and mass producing at a nanoscale. Some of the most famous basic technologies to date include scanning electron microscopy (SEM) and nanotubes as a basic construction material for everything from stronger, lighter tennis rackets to the space elevator.

In this research, we are interested in examining how these two fields, biotechnology and nanotechnology, have diffused internationally, and further downstream at the country level in order to understand which factors have impacted their diffusion. The literature has operationalised diffusion in a multitude of ways, depending on the discipline, including the unintentional movement of matter (for example, the movement of a given disease) or the intentional movement of people, information, artefacts such as technology or goods, and so on [see Niosi et al. (2010) for an elaboration and synthesis of the literature on this topic] and is often conceptualised as movement across borders and into/out of countries. Diffusion, according to social scientists, is conceived differently as a process whereby the members of a social system influence one another in direct and indirect ways (i.e., through demonstration that creates awareness, through providing information that shows viability of a new technology or product, through competitive pressure, etc.). According to Rogers and Shoemaker (1971), diffusion is a special type of communication. From a network perspective, then, it is the process by which innovations spread to members of a social system. Following scholars such as Burt (1992), Attewell (1992) and Allen (1977), the dominant explanation for the spread of technological innovations emphasises processes of network influence and information flow. The network development, which occurs alongside the development of a technology, is therefore a type of diffusion, and offers the best lens through which key factors influencing the diffusion of emergent technologies may be examined.

With emerging technologies, informal and formal network connections through industry-wide associations (professional societies, trade associations and standards bodies), cooperative research associations, and other university-industry-government involvement (Garud and Kumaraswamy, 1995; Tushman and Rosenkopf, 1992; Farrell and Saloner, 1988) are essential coordinating mechanisms initiating generic technology development and diffusion. These types of relationships comprise networks of learning (Powell et al., 1996) and are the critical impeti largely impacting the initial ‘sending end’ of messages transmitted out along the innovation network.

One of the key factors impacting growth, involving path-dependent technology development processes (David, 1985; Dosi, 1988), is the ‘network effect’. Simply put, the driving force behind the power of networks is the following: the benefit of adopting a new technology varies directly with the number of others who adopt the technology (Katz and Shapiro, 1985; Hunt and Morgan, 1996). As an example, to put this in layman’s terms, the success of various waves of computer programmes such as Microsoft Word can be attributed to this effect, as individual users want to be able to share documents and work together in the easiest way possible and this is best facilitated when everyone speaks the same ‘technology language’. Thus, technologies which gain steam tend to be those which corner the market of potential adopters; in the case of the emergent technologies of interest in this research, these would initially be scientists, researchers, engineers, doctors and so on. When such individuals work together, they need to be on the same page with as many other individuals in their network as possible, in terms of the generic technologies which they understand and access; and so, the network effect is a powerful process which drives diffusion of technologies.

Rogers’ (1983) framework provides a useful tool for understanding the factors that most impact rates of diffusion through the network effect. According to Rogers (1983), the speed of diffusion is influenced by five characteristics of innovation: relative advantage, complexity, compatibility, trialability and observability. These qualities of the initial networks in the life of an emerging technology will determine the initial speed of transmission of the technology message. In other words, they will determine the progenitor technologies that will largely influence the development of the technology (and, therefore, largely influence its’ level of complexity). The dispersion of the network also impacts the level of persuasion that is possible towards adoption of the technology.

1.1 Central research question and related hypotheses

The key question which this research seeks to answer is related to how information flow rates, country-level dispersion of networks and complexity of generic technologies (based on number of progenitor technologies) impacts technology diffusion rates. The central premise of this paper is that while enhanced rates of information flow have generally increased the ability for international players to enter various technology development trajectories earlier than once was the case, particularly in terms of their scientific contributions, these same trends are creating more dispersed networks which suffer from the concomitant problems associated with information flow in such diffuse situations – particularly, such dispersed networks impact flow at the country level. Dispersion specifically impacts levels of trialability and observability achievable through demonstration from one network actor to another. So, in plain terms, while artefactual information may be available in the form of patents and publications on a worldwide level, the ability for people to work face-to-face together on projects in order to transfer skills, is difficult in dispersed networks; and it is 'learning by doing' (trying, observing) that needs to be better facilitated – through proactive collaboration – in order for effective diffusion to take place. Specifically therefore, it is hypothesised that the more dispersed the overall network for a technology, the slower the diffusion of the technology at a given country level (H1).

A second proposition of this paper is that a further key factor affecting the rate of diffusion of technology trajectory development involves the number of progenitor technologies which are combined to create the new technology. The specific impact on rate of diffusion is proposed to be related to the level of complexity of the integration of these progenitor technologies (H2).

2 Methods

The above-mentioned hypotheses were proposed based on a comparison of two critical technological trajectories – one, from biotechnology, and a second, from nanotechnology (Reid and Pliniussen, 2002) conducted ten years ago. The data sample from the original research included the first 100 patents of the earliest important generic technologies underlying these two emerging fields under investigation: recombinant DNA for biotechnology and nanostructures for nanotechnology. The data collected in the original sample were collected during 2001, using key words, and represented patents filed over a 20-year period and happened to be filed exclusively by developed countries, with the exception of a number of Chinese patents held in the nanostructure space. The patent data were obtained from the US Patent and Trademark Office.

For the current paper, it was of interest to see whether the comparison between biotechnology and nanotechnology diffusion rates held with a second data sample taken from the same emergent fields, but at a later point in time and from a developing country, India. It was projected that this second sample would have been influenced by the first sample which was collected from the first 100 patent filers each for recombinant DNA and nanostructures.

3 Results

In the first study conducted by Reid and Pliniussen (2002), biotechnology, measured by the rate of growth of patenting activity in the area of recombinant DNA, considered to be the single largest leap in terms of a new technology giving life to a new industry, basically reached the 100 patent mark within eight years, starting with a first patent applied for in 1978 and issued in 1980. Nanotechnology, on the other hand, was measured by the rate of growth of patenting activity in the area of nanostructures, and took approximately 20 years to reach 100, starting with a first patent issued in 1981. By fixing the number of patents, it is possible to see that the rate of technological progress and diffusion has been far more rapid for biotechnology than for nanotechnology.

Technology life cycles are usually identifiable as 'S-curves', whereby the bottom of the 'S' represents 'new invention' or the 'basic research period' of a given technology, the middle of the 'S' implies technology improvement or the development period and the top of the ‘S’ curve represents mature technology (Ettlie, 2000). Christensen’s (1992) technology ‘S-curve’ theoretically captures the “potential for technological improvement … resulting from a given amount of engineering effort”. It is not a measure of sales growth; it is a measure of the rate of technological progress, and therefore is inherently an institutional-level process. The potential at the beginning of the technology life cycle is quite great and then, at the end of the life cycle, increasing engineering effort has diminishing returns to performance of the technology (Ettlie, 2000). The mathematical expression which best captures this growth tendency can be written as follows:

$$\mathrm{Y} = \mathrm{L} / 1 + \mathrm{a}e^{-\mathrm{bt}}$$

Y	rate of change of technological progress
L	value of the curve at the upper limit for the growth value
e	base of the natural logarithm
t	time
a, b	coefficients that fit the data curve.

Based on this same data, it was also noted in Niosi and Reid (2007) that fewer than 20% of the patents granted in the field of recombinant DNA were granted to foreign patent applications (outside the USA). Additionally, those foreign patents were not dispersed widely across several countries. Rather, the foreign patents were concentrated solely in Japan and a couple of European countries, and these were mostly one-off contributions. In comparison, the first 100 patents granted in the area of nanotechnology have been widely dispersed in terms of networks – approximately 45% having been granted outside of the USA. This wider dispersion, according to Niosi and Reid bodes well in terms of a better seeding of future product capabilities across countries. The question is whether such dispersion slows down the diffusion process within a given country?

As such, for the second data sample of interest in the current paper, the same progression was investigated for a developing country: India. All Indian biotechnology patents were investigated for the period starting in 1995 post-TRIPS when patenting began in earnest. The USPTO statistics from 1995 to 2007 are shown below in Table 1 for biotechnology and show that it took essentially just over nine years to reach the 100 patent mark. Interestingly, this is not too far off the eight-year period noted for the first 100 patents awarded in recombinant DNA (biotechnology). Additionally, as with the first sample, nanotechnology has progressed at a much slower rate in India as shown in Table 2. According to the USPTO, from the period 1998 until 2008, 24 patents total have been filed in the nanotechnology space by Indian entities. At this rate, it will take another 30 years before reaching the 100 patent mark.

Table 1 USPTO total Indian biotechnology patents

Total	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
208	1	1	2	6	7	6	15	27	31	23	23	33	32

Source: USPTO [searched by Niosi et al. (2010)]

Table 2 USPTO total Indian nanotechnology patents

Total	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
24	0	0	0	0	2	2	2	2	4	4	6	2	0

Source: USPTO

Even adding in additional patents awarded through PCT and EPO available from the OECD, the total number of nanotechnology patents awarded to India through the period 1995 to 2007 does not achieve the 100 patent mark, as indicated in Tables 3 and 4.

Table 3 Nanotechnology PCT patents

Year	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*Total*
World	903	1,220	1,371	1,471	1,745	1,652	1,230	9,592
India	2.4	2.3	6.5	17.4	7.4	6.8	9.5	52.3

Source: OECD Statistics 2009 (van Beuzekorn and Arundel, 2009)

Table 4 Nanotechnology EPO patents OECD

Year	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
World	877	1,055	1,195	1,169	1,317	1,222	630
India	2.1	2.5	3	11.3	4.1	3.6	4.8

Source: OECD Statistics 2009 (van Beuzekorn and Arundel, 2009)

4 Discussion

As noted by Kogut (1990), technological advantage in various industries is heterogeneously distributed among countries and this pattern tends to persist over time. This tendency has been particularly evident in the USA with the biotechnology industry where, not only are research networks quite central, but they are also clustered quite strongly around a few key public and private institutions, or ‘anchor tenants’. The centrality and strength of the US biotech networks was built up around common language, and the ability to spend long and intimate time together at conferences, meetings and during cooperative research work. As such, these researchers operating in close cooperation likely had the ability to ‘observe’ and ‘try out’ techniques and theories with other researchers, building on strengths of trialability and observability. Further, the different underlying technologies, which combined to give us recombinant DNA differed mostly in degree and emanated almost exclusively from the field of molecular biology, thereby building on capabilities that already existed amongst the research population. As such, relative advantage and reduced complexity, in terms of progenitor technologies, allowed even further increase in diffusion rate.

In contrast, the field of nanotechnology has progressed at a much slower rate. In comparison to the less than 20% of first recombinant DNA patents granted to foreign entities, the first 100 patents granted in the area of nanotechnology have been widely dispersed in terms of networks – approximately 45% having been granted outside of the USA. This finding demonstrates that while enhanced rates of information flow and the existence of global manufacturing facilities have increased the ability for foreign players to enter technology development trajectories earlier than once was the case, these same trends are creating more dispersed networks suffering from poor communication, despite access to telecommunications. Secondly, it is likely that diffusion of nanotechnology has been hindered by the lack of strength between nodes in the network. In other words, the dispersion of work across many countries is impeded by the variety of language and the inability for different research groups to come together for long periods of time, thereby impacting the potential for trialability and observability, such as that which would be possible in the USA. Thirdly, the different underlying technologies, which contribute to the field of nanotechnology, vary both in kind and degree – having bases in molecular biology, electronics, materials, and physics (optics and quantum), to name a few. As such, rather than nanotechnology diffusing more rapidly than biotechnology, the opposite has been the case.

The net result has been that diffusion rates, although sped up by access to information, and also, arguably, because a background in biotechnology would set a platform for some entries in nanobiotechnology, are more slowed down by lack of network centrality and network strength generated by the dispersion of information networks. These findings suggest that both the more diffused network involved with nanotechnology and the technological development involved with combining multiple generic technologies into one new technological path, may have a greater combined differential impact on diffusion rate than increased information flow in networks. Let us now look at the specific case of India.

4.1 Indian biotechnology networks

According to Reid and Ramani (2010), biotechnology in India was introduced and adopted through public policy (as a result of individual informal networks) rather than individual firm initiatives. Specifically, in 1982, individual members of elite research laboratories, who were aware of developments in the USA and Europe, petitioned the Indian government; this informal network and its lobbying of the government led to the creation of the National Biotechnology Board (NBTB) which formulated a road map for biotechnology in India. Until the mid-1990s, coinciding with the adoption of TRIPS, public policy was largely focused on the creation of scientific capabilities and the building of awareness of the potential of biotechnology.

The literature (Chaturvedi et al., 2007; Frew et al., 2007; Kumar et al., 2004; Mani, 2004; Mytelka, 2006; Ramani and Venkataramani, 2001) demonstrates an overall definite and positive trend, with respect to policy and spending in the public sector. Most authors purport that there is an excellent tradition of scientific education in India and additionally, that India is moving in a positive direction with respect to patterns of basic biotechnology research funding, and national technology and regulatory policy. The output from these efforts has been impressive on several levels including figures of production of graduates and publications. For example, according to Reid and Ramani (2010), India has shown good growth in biotechnology publications from 1996 to 2007 starting at 495 articles in 1996 and growing to 2,065 published in 2007, with a total during the period to mid-2008 of 14,532. In comparing these totals to the world total for the same period, the growth went from 1.5% of the world total in 1996 to 4% by 2007, thereby illustrating good growth. As such, we can see that by any measure, India has clearly set the stage, on the whole, in order to promote the absorption and diffusion of scientific capabilities in biotechnology.

A key question at this point is whether such promotion of diffusion of scientific capabilities has been able to progress further downstream? Information flow rates, as noted, are impacted by several factors, and an important one is through alliances. According to results available from the OECD (2007) for overall international co-authorship ratio citings across disciplines from 1999–2004, the EU has clearly 'caught up' in terms of publications and citations; and both the Asia-10 and Central/South America are showing very strong growth from 1995 to 2005 where the USA. has declined slightly in growth by comparison. India clearly could improve on this count, showing up only in the bottom 10 on the OECD list and this shows evidence of a weakness in terms of cooperation capabilities. Specifically, for the biotech sector, while the number of publications by Indian institutions has shown an increase year-on-year, the inter-country collaboration has not changed over the period, and in fact have shown a slight decrease over the period as a percentage of total articles in collaboration (106/495 = 21% from 1996 compared to 322/1,856 = 16% for 2007) (Niosi et al., 2010).

Additionally, as noted with the patent results, the majority of USPTO patented biotechnology during this period was performed by public institutions. The vast majority of the USPTO patents for India are awarded to universities and public laboratories (195 out of 208) while companies are just starting to enter the game, as indicated in Table 5.

Table 5 Indian biotech assigned patents, USPTO 1979–2007

Date	*Total USPTO Indian biotech patents*	*Corporate USPTO Indian biotech patents*
1979	1	
1995	1	
1996	1	
1997	2	
1998	6	
1999	7	
2000	6	
2001	15	1
2002	27	
2003	31	1
2004	23	1
2005	23	3
2006	33	7
2007	32	
Total	208	

Source: USPTO [searched by Niosi et al. (2010)]

While the landscape has changed during the last 15 years, with several Indian firms moving into the biotechnology space, patenting has remained largely in the domain of the public sphere. Most leading Indian firms have, rather, commercialised generic versions of original innovations developed by US and Japanese firms, or have focused on developing vaccines. These large Indian firms have additionally focused on exporting as a strategy and for several top firms this has paid off in terms of impressive revenues. For example, the top three Indian companies in 2008/2009 enjoy impressive revenue from sales: Serum Institute ($250 million USD), Biocon ($205 million USD) and Panacea Biotech ($134 million USD) (Bio-Spectrum-ABLE, 2009). Additionally, a number of firms have focused on the CRO route, providing pre-clinical, analytical and/or clinical services to Western and Japanese MNCs. While these firms have impressive revenues, their patenting record remains meagre. Also, according to Niosi et al. (2010), more than two thirds of biotech patents awarded by the USPTO to Indian inventors are attributed to US assignees (universities, research laboratories and companies), and are therefore not captured in the Indian company assignations.

The story is different, however, for international PCT filings (EPO designations). According to van Beuzekorn and Arundel (2009), India from 2004–2006 applied for 423 biotech patents (applications based on priority date and inventor's country of residence). This represents 423/11,310 total filings for India in that period or almost 3.75% This compares to seven biotech filings out of a total 49 in the period during 1994 to 1996, thereby showing a drastic increase in filings since that time.

Further, the corporate landscape appears to be changing – in the 2009 Bio-Spectrum-ABLE (2009) top 50 report, 11 of the top 50 companies in terms of sales revenues from 2008 to 2009 were new companies (either new spinoffs from large pharma, or brand-new players) in the last three years and this new cohort appears to understand the value of patenting.

Interviews which were conducted by Reid and Ramani (2010) further revealed that there are various holes in the innovation system, particularly in terms of networking capabilities, which appear to have an impact in terms of obstructing the diffusion of technology capabilities, and this may have an impact in terms of patenting outcomes. Among the challenges mentioned in these interviews, the two issues mentioned most often were regulatory issues/lack of infrastructure and lack of capital. Another issue mentioned often was that while the abundance of training provided at the university level was good theoretically, it did not translate into a well-skilled labour force able to work in teams and this has fleshed out in terms of low patent levels from companies within India by Indian inventors and also by the low levels of coop arrangements with other countries and companies.

4.2 Indian nanotechnology networks

Interestingly, one of the major differences with India's entry into the nanotechnology race, and a major accounting for the slow diffusion of this technology into India, is that it has done so at a much later point than it did relatively speaking when compared to biotechnology – this is particularly interesting given that there is overlap between the fields of biotechnology and nanotechnology, and yet, public policy aimed at entry into nanotechnology has sadly lagged behind many other countries. An official public policy aimed at supporting the development of nanotechnology in India was only launched in 2007 (Ministry of Science and Technology which also houses the Department of Biotechnology launched an official National Nanotechnology Program) whereby, according to Niosi and Reid (2007), $15 million was allocated for Smart Materials development and DST funding was $10 million from 2007–2010. This is a drop in the bucket in comparison to other countries led by the USA, which through the National Nanotechnology Initiative, launched in 2001, has spent $1,527 million in 2009. In total, over $4 billion dollars of world-wide government funding has been pumped into the nanotechnology sector in 2008. This total \$25 million investment in Indian nanotechnology sector just will not cut it when it can cost in excess of \$1 million just to outfit one lab with a few key pieces of equipment. This may be one reason for the lack of progress made in nano-patenting in India. As we see from the results section, patenting in the nanotechnology space has been very slow and sporadic. A mere 24 nanotechnology patents were filed during the entire period 1995 to 2007. Even the PCT filings were just over 50 for India, representing a 0.005% share, which is not strong, considering its share of publications in the nanotechnology sector, its involvement in biotechnology and its population.

Despite their meagre investment in nanotechnology and a lack of collaboration with other players, India has something to show for its investment to date in the nanotechnology space. According to various sources (Kay and Shapira, 2009; Porter et al., 2008), based on an analysis of the Georgia Tech global nanotechnology publication dataset, during the period 1990–2006, the USA held 22.5% world share of all nanotechnology publications (101,205), and the other leading countries in descending order are China (11.5%/51,620), Japan (10.6%/47,894), Germany (9.3%/41,793), Spain (2.1%/9,675), India (2.1%/9,399) and Brazil (1.2%/5,456). It may well be, however, that India's ability to perform in publications is a reflection of some of the previous biotechnology investment where articles are being written in the area of nanobiotechnology, and this will prove an interesting avenue to investigate in future research. Further, as with the biotechnology sector, this early diffusion of nanoscience in India represented by share of publications on the world scale, does not necessarily reflect a deeper ability to absorb and transform these early skills through social capabilities.

As an example, a further problem appears to be that India has no concrete programmes for interacting with other countries in developing formal government-led inter-country nanotechnology networks. Additionally, they have not learned an important lesson from one of the main failings in biotechnology: lack of collaboration in terms of informal and formal networks at the corporate level. For example, Patra et al. (2010) investigated the perceptions of 58 nanotechnology practitioners in India and found only one from industry that felt that nanotechnology had been incorporated into the R&D programmes of Indian firms. Further, as noted by Ramani et al. (2010), of those interviewed, 60% felt that unresolved 'ethical' issues were another problem that needed to be addressed in order for diffusion to occur.

5 Conclusions

While there are certainly many challenges for countries interested in being involved with new emerging technologies, including public funding in meaningful ways, gaining access to venture capital, regulatory infrastructure and access to markets, a key ingredient in terms of moving diffusion along is enabling the diffusion of information through networks in unimpeded ways. Specifically, the impact of geographic dispersion of capabilities between countries must be lowered either through support to encourage co-authorship, availability of ideas through access to knowledge of ongoing patenting activity worldwide and university or corporate alliances or hiring of expertise from abroad, encouraging international investment and so-on. The primary focus here is on the development of human social capabilities and this requires the greasing of networks through shared space and time, primarily through informal and formal collaboration and alliances. Networking and collaboration are central to increasing information flow and also, to overcoming some of the challenges provided by complex generic technologies such as in the case of nanotechnology, founded on multiple progenitor technologies. In effect, these mechanisms help to overcome some of the effects of dispersed networks.

Are there still windows of opportunity for India in biotechnology and nanotechnology? The outlook, at least at first glance, for biotechnology appears to be more promising on several levels than nanotechnology, but there is also a time lag which nanotechnology is dealing with in India, so it may be too early to judge. Additionally, Niosi and Reid (2007) have made a case that several of the scientific and social capabilities are already in place to have an overall positive impact on absorptive capacity; large populations of engineers and doctors, universities and public institutions that have started working on nanotechnology, English as the key language of work and some extant technological capabilities (i.e., some in software, some in biotechnology, and others) that can be leveraged in future. A key question is whether the public and financial institutions will act as a bullwhip to help build on these capabilities and whether there will be a move to building capabilities in collaboration and alliance networking in the future.

6 Future research

The greatest challenge perhaps for academics and practitioners interested in trying to influence rates of diffusion, is to be found in network strength areas such as ‘coupling time’ (Weick, 1976), ‘intimacy’ (Victor and Blackburn, 1987), and common language. The coupling concept has been used extensively in organisational research. Loose coupling occurs when parties affect each other suddenly, occasionally, negligibly and eventually. Tight coupling occurs when the parties affect each other continuously, constantly, significantly and immediately. Network systems can be viewed as tightly or loosely coupled. It may be possible to develop these concepts more concretely, in a way that can be measured. Intimacy, is a measure of mutual confiding, and becomes important to the level of persuasion and demonstration possible in a relationship. Common language is a third concept which will impact network strength and is likely correlated with achievable intimacy. Each of these concepts needs to be examined in more detail in future innovation network research. There must be synergetic creation of new knowledge and technology with the rest of the world. Finally, several of the potential ‘amplifier effects’ such as effective public policy mechanisms, international collaboration and more dense within-country networks, might be tested in the future in terms of their actual impact on increasing technology diffusion rates.

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