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Nanotech after Biotech in Emerging economies: Déjà vu or a new form of catching up?

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Abstract

In this concluding chapter, we briefly outline the biotechnology experience of the leading Latin American countries to identify some of the lessons learnt. Then we examine to what extent these have been incorporated in the policy designs of emerging countries to catch-up in nanotechnology. We draw upon the case studies presented in this book to propose the answers. We conclude that while clearly the emerging countries have made inroads into building dynamic capabilities in nanotechnology, a number of institutional challenges remain. These are of missing or inefficient institutions, ineffective incentive systems and inadequate regulatory protocols. Addressing these challenges will help improve capabilities, increase returns to scarce resources and enable their national systems of innovation to cater better to local needs and aspirations.

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1. Introduction

Modern biotechnology or third generation biotechnology refers to a set of techniques involving manipulation of the genetic patrimony of an organism such as genetic engineering (recombinant DNA technology, monoclonal antibody techniques, gene synthesis), cell and tissue cultures, protein synthesis and enzymology. As a technological revolution it preceded nanotechnology by about 30 years. The two technologies share a number of common features. Like biotechnology – nanotechnology is a set of generic-platform, general-purpose technologies with potential applications in many sectors. Alone and together, they have the potential to profoundly change the mode of production in almost all industries while being the motors of economic growth with inclusive development. Both are highly science-intensive, and equipment-intensive, requiring cooperation between scientists from various disciplines for innovation generation. From the 1980's, when it became evident that biotechnology as a generic technology would be crucial to economic power and national competitiveness, emerging countries also began to invest in it and accumulate experience. Since nanotechnology is so similar to biotechnology in terms of the challenges presented for their integration into strengthening industrial capabilities, it is natural to enquire: what are the lessons that emerging countries have learnt from their biotechnology experience? Have the lessons been incorporated into policy design for better performance in nanotechnology?

We respond to the above query in two parts. We first briefly examine the biotechnology experience of the leading Latin American countries to infer the lessons learnt, as it is beyond the scope of this chapter to look into the biotech histories of all emerging countries. Then, we turn to the nanotechnology performance of emerging and developed countries as presented in this book to reflect upon the second question.

2. Lessons from the biotechnology revolution: the Latin American perspective

Modern biotechnology emerged during the late 1970s from developments in the biosciences such as biochemistry, biophysics, molecular biology, microbiology, cellular biology and genetics. During the 1980s and 1990s, genomics, proteomics, bioinformatics and stem cell research were added in fast succession. The first biotech companies were formed in the USA, which is still the acknowledged leader in many biotech niches. From the mid-1980s emerging countries with scientific capabilities also joined the international race to develop capabilities in biotechnology.

After nearly 30 years of engagement, the diffusion of biotechnology among the emerging countries, including those in the Latin American region remains highly uneven. In biotechnology, Argentina, Brazil and Mexico are among the leading countries in Latin America. While they share some similarities, they are more distinguished by major differences.

In all three, the stock of scientific publication has increased very fast, and much faster than in the world (Niosi et al, 2012). This indicator shows that some catching up has occurred at least at the level of the academic institutions. The academic catching up process is much more pronounced in Brazil than in the other countries. This could be because Brazil has been consistently investing over 1% of GDP in R&D, with the federal government bearing the major part of the effort.

Another similarity is the fact that biotechnology patenting is extremely low in the three countries. Low patenting indicates that the research results are most often not patentable, which in turn either means that most innovations are incremental or that the countries have low patenting capabilities. Moreover, most of the patents invented by Latin American researchers belong to North American and Western European firms and universities. In other words, Latin American researchers are sometimes able to execute R&D projects with radical innovation components, but these projects are designed and funded by richer and more advanced institutions and companies based in Canada, Europe and the United States.

Coming to the differences between the three major countries, we note that they are staggering. In Brazil, biotechnology development is basically a State initiative. It occurs in such institutions as EMBRAPA (the Brazilian agricultural research institute) and the FIOCRUZ Foundation (specialized in human health biotechnology). EMBRAPA is the source of most Brazilian GMOs[1]. FIOCRUZ conducts research and manufactures drugs for the public human health institutions. Universities – particularly the large federal ones – are also active in biotechnology research. Conversely, private sector organizations (pharmaceutical firms, dedicated biotechnology firms, farms, and hospitals) have very little research activity. This is due to the fact that policy incentives are not strong enough to overcome resistance to conduct in-house R&D due to the risk and uncertainties linked to this activity. Also, many of the largest domestic pharmaceutical firms have been absorbed by foreign multinational corporations that have curtailed internal R&D and prefer to import products and technologies from their head offices. Some authors have underlined the fact that, under such conditions, the private sector seems to be weak and unable to absorb the technologies produced by the public institutions (Rezaie et al, 2008). However, in the agricultural sector, as in many other countries, public research has been conducive to the diffusion of new GMOs, and Brazil has now become the first Latin American country in terms of surface planted with GMOs and a major exporter of genetically modified soya.

In Mexico, also, private sector R&D is weak, for similar reasons as in Brazil, but Mexico has no equivalent public sector research powerhouses as EMBRAPA and FIOCRUZ. In Mexico, biotechnology research takes places in the largest academic institutions, particularly at the National University of Mexico, in Mexico City. When normalized by population, the stock of Mexican biotechnology publications is much smaller than in the other two countries. Thus, Mexico does not produce biosimilar drugs nor it has adopted genetically modified seeds in its agricultural sector.

Argentina again is different. Foreign corporations did not absorb its pharmaceutical industry, which is the most advanced in the region. Some ten domestic private firms are now producing and selling biopharmaceutical drugs, and the country has a positive trade balance in medicines. In July 2012, the largest domestic pharmaceutical group, INSUD, inaugurated the first Latin American manufacturing plant for monoclonal antibodies. However, public regulation of such drugs is poor: there are no compulsory clinical trials for these biosimilar products, that are thus unable to compete in OECD markets and are only sold in other unregulated markets in Latin America, Africa and Asia. In agricultural biotechnology, Argentina has also been a fast adopter of GMOs, and is now the third country in the world,

[1] Genetically modified organisms

after the USA and Brazil, in terms of its transgenic crop area, well before India, Canada and China (Nature Biotechnology, 2012, 30 (3): 207).

This brief incursion confirms the main challenges that have been generated by the biotechnology experience for all latecomer countries. These are associated with the need to satisfy at least four conditions in order to build industrial capabilities in a new science based industry.

Condition 1: The scientists are up to date in the disciplines constituting the foundation of the particular science based industry. Universities and public research laboratories have to ensure an adequate quantity and quality of scientists, who are also up to date in the required scientific fields. This will not only depend on the magnitude of public investment but also on the 'incentives' prevalent for scientists to perform, as well as on the hiring practices of these institutions. In other words, State investment in education is a necessary but not sufficient condition for the creation of scientific capabilities in elite institutions. This is clearly reflected by the uneven generation of scientific publications in biotechnology within Latin America and in comparison to the rest of the world (see table A1 in the appendix).

Condition 2: There is mobility of resources (information, labour, people and capital) between the research market formed by the creators of knowledge and the product market formed by firms involved in manufacturing. The degree of cross fertilization of effort between the creators of scientific knowledge, usually public laboratories and universities; and the creators of products and processes for economic use, usually firms, will depend on the nature of the links between them. Unless there are active exchanges between these two actors, scientists may overly focus on abstract research which yield scientific publications but otherwise have little economic potential. If industrial researchers are not up to date and competent on the latest research, they would neither be aware of the technical potential of research output nor have the capacity to absorb the scientific results and transform them into usable technology. This is clearly evident given the low level of biotechnology patenting in Latin America.

Condition 3: There are incentives for conversion of research output into product or process innovations. Any costly R&D investment, whose returns are uncertain, will be undertaken only if the expected profit is of a particular magnitude. Expected profit is determined by a number of technological, firm and market features such as: possibilities for imitation, organisation specific competence, production capacity, market share, market structure, market competition, level of entry barriers, ownership of required and complementary assets and macro factors such as government subventions, government regulations, intellectual property rights, functioning of financial markets etc. The sum result of the interaction between these parameters must be so as to result in a high enough profit to make R&D investment worthwhile.

Even if scientific capabilities are built, there is no magic bullet to get the private sector to move, though efficient science-technology-innovation (STI) institutions may be helpful. As proof, we can refer to countries in Europe and Asia (India, Korea, Taiwan etc.) which have developed an active biotechnology sector[2]. The most remarkable set of late-comers are the East-Asian countries. Despite having entered the biotechnology race much later than the

[2] See Reid and Ramani, 2012 for India; See DeLooze and Ramani, 2002 for France, UK and Germany.

major Latin American countries, South Korea, Singapore and Taiwan, are now far more advanced than them in terms of academic publication, patents and commercial biotechnology applications, particularly in the human health sector. This could be in part due to their highly skilled permanent and meritocratic government departments, which worked to create the favourable conditions for capability-building.

Condition 4: There are agents in the economy (the government, the public, the firms or the capital markets) who are willing to bear the cost of risky R&D investment. R&D effort for any firm is distinguished from other activities such as manufacturing or marketing, in that it is essentially a search activity on which an efficiency criterion cannot be imposed. As a search activity its output is uncertain and therefore an R&D investment involves risk. When the degree of risk is high, it may not be possible for an individual firm to bear it. In such cases the sector will not grow the risk is shared with other agents such as venture capitalists, the public, or the government.

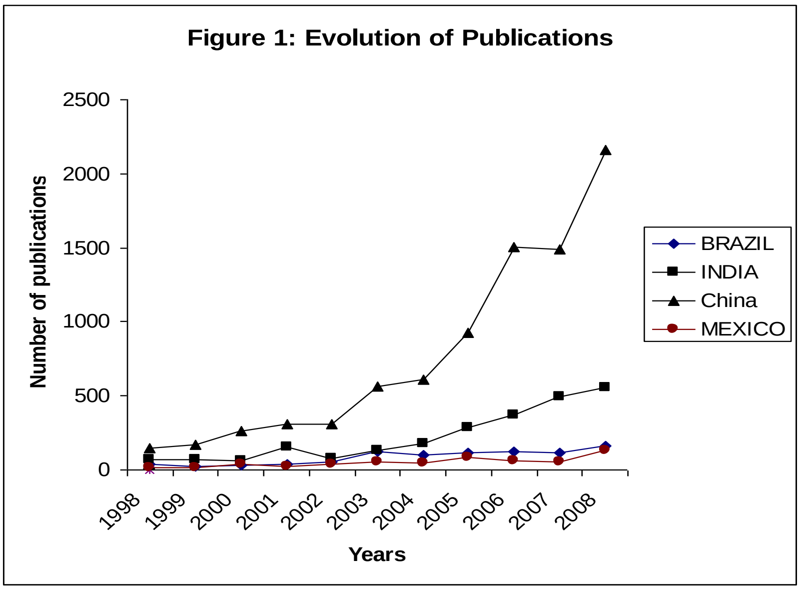
In most OECD countries, governments share the cost of industrial R&D through many different schemes such as direct non-reimbursable subsidies, reimbursable loans, and tax credits for R&D, and they have launched, assessed and fine-tuned these incentives over several decades after WWII, to insure that private firms establish in-house R&D facilities. In contrast, in Latin American countries, behind ineffective and inefficient STI policies, one finds a low quality, high-turnover public sector bureaucracy, unable to design, apply, evaluate and modify these key development policies. Public servants, who are continuously changing from one government department to the next, are usually not able to understand the complexities of these policies and the multiple positive and negative feedback effects these policies trigger. Devising an effective tax credit for R&D system that can promote R&D activities in private firms is not a task that public servants with six or twelve months temporary contracts can do (Niosi, 2010 and 2010b).

Let us now turn to the nanotechnology experiences of emerging countries.

3. A comparative analysis of the emerging country trajectories

In Brazil, China and India, the creation of scientific capabilities in nanoscience and nanotechnology (NST) in the form of new research institutions were exclusively financed by the government under programs uniquely devoted to NST. University programs were also set up to create qualified graduates. In Mexico scientific capabilities in NST were created not only by governments (both Central and State) but also by international non-profits like FUMEC under a variety of national programmes not exclusively focussed on NST. These efforts have all borne fruit as shown by figure 1. Using the Science Citation Index Expanded (SCI-EXPANDED) for the years 1998-2008 and the same research equation as in chapter 2[3], figure 1 presents the evolution of NST publications from the four countries. China leads the pack, followed by India, with Brazil and Mexico dovetailing each other.

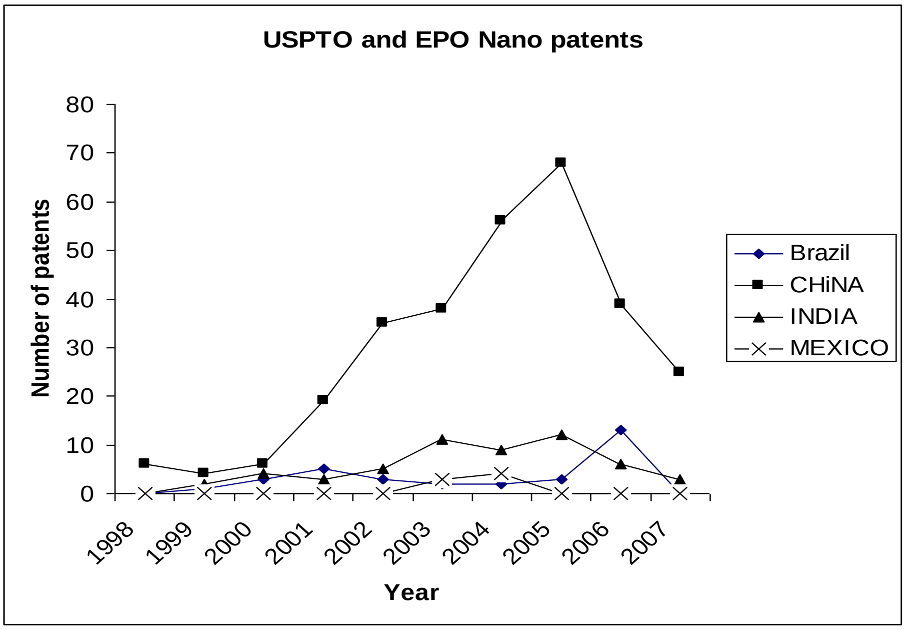
[3] With document type: All and Field: country in question,



The above trends are proof of the existence of highly dedicated and capable scientists in all the emerging countries studies. The creation of scientific capabilities is the major strength of the emerging countries.

Has this expansion in the knowledge base and skills set been transformed into technology with a commercial potential? Transformation of knowledge into innovation is a big challenge for any country. Each of the case studies revealed a very small but nevertheless visible participation, of firms co-publishing with public laboratories. The activity of firms is marginally greater in terms of patent applications, a measure which partially captures the magnitude of technological capabilities of a country (see figure 2[4]). Again China is in a league by itself and despite being in the 'lower middle' of middle-income countries according to the World Bank, in terms of scientific and technological prowess it has emerged as an international leader. Thus, we can clearly conclude that the four countries have nascent technological capabilities. The importance of public-private collaboration in developed countries was also reinforced (chapter on Korea and Germany), further revealing how government support can lead to different patterns of collaboration. In Germany, the gatekeepers of the knowledge circulation seem to be public sector research stalwarts, while in Korea the private sector organizations have taken the lead in building clusters of collaboration.

[4] Obtained from MicroPatent's PatSearch FullText Database; Country patents identified through field 'Priority data' using the iso code of the country. Priority date taken as earliest. USPTO Granted & Applications. And EPO : EP-A EP-B WORetrieved in September 2009



**Figures for 2008 are incomplete.*

Finally, it is impossible to compare the NST market size in emerging countries because of a lack of data. The case studies indicate that the private sector seems to be more active in India and China than in Latin America. In China, there is a strong support from the government for A to Z of the commercialization process. Indeed, China's strength is in terms of the sheer magnitude of State investment and this push is leading to a quiet integration of NST based processes in selected niches such as solar energy. In India, firm strategy is much more heterogeneous and independent of State support, responding instead to market demand signals. Thus, it is not surprising that Indian firms are making a name for themselves in the generation of original disruptive innovations even in nano[5].

On the negative side, all the emerging countries exhibit the following shortcomings though of varying degrees.

In terms of scientific capabilities, each country can boast of a few premiere scientific institutes but these are surrounded by many poor to very poorly performing scientific institutions. Low salaries and hiring practices that are not meritocratic act as obstacles to attract top-level scientists (except in China – thanks to a massive academic reform). More nano graduates are being produced than can be absorbed by industry (e.g. India).

Coming to policy design, there is broad base funding to scientists without concrete targets. The absence of concrete national targets in terms of innovation generation towards which effort can be focussed is of concern, as the opportunity cost of funds diverted to any scientific endeavour is much higher for emerging countries with high poverty burdens. Moreover, there are too many parallel initiatives that disperse resources and chances of results. Allocation to NST vacillates according to the varying fortunes of the political parties in power in Latin America, while the high turnover of bureaucrats presents a challenge to implementing a long term strategy in all the emerging countries studied.

[5] i.e. new designs of products, processes or business models whose quality and performance do not match their high-end counterparts, but which nevertheless creates new markets or captures the market.

Weak capabilities to design, implement and assess STI policies plague the effectiveness of public agencies. There is a serious shortage of manpower in patent offices as there are not enough people with knowledge of the science, the law and the industry. There are regulatory loopholes, and even for the existing regulation, it is difficult to ensure compliance.

With respect to the private sector, the major challenge is a low level of investment, indicating a low of interest that could stem from a lack of awareness and/or the lack of market mechanisms like an active venture capital market to share the risks of incorporating a new technology in the production process.

4. Concluding remarks: On catch-up theories and existing macro-beliefs

We now return to the main question of the chapter. How has the biotechnology experience shaped the participation trajectory of the emerging countries in nanotechnology? Three main lessons seem to have been learnt by emerging countries from participation in the biotechnology revolution. First, emerging countries with established scientific capabilities cannot afford to adopt a ‘wait and see’ position to plunge into a revolutionary technology paradigm like NST with such economic potential. Especially, since emerging countries already have scientific and technological capabilities in material sciences of which NST forms a part, and there is a heightened awareness following the biotechnology revolution, all countries have jumped into the nano bandwagon with much less delay than they had with biotechnology. Second, unlike the participation in the biotechnology revolution which could be termed ‘slow and steady’, most governments spent heavily on building NST capabilities right from the start. Third, all the societal stakeholders (chapters on Brazil, India and France) are more aware of the potential risks of NST thanks to societal debates over genetically modified plant and animal varieties resulting from adoption of biotechnology. Therefore, there has been more societal dialogue on the technology acquisition and incorporation protocols right from the beginning. However, like in biotechnology, there is no consensus as of yet.

The case studies presented in this book nevertheless clearly show that the heavy investment in NST by emerging countries is neither rooted in solid forecasts of when nanotechnology can be widely commercialized nor backed by confidence in the capacity of indigenous firms to integrate the scientific capabilities accumulated in the country (chapter on China). Rather, they are emulative strategies whose objective is to build dynamic capabilities in NST and catch-up with other advanced countries through massive public investment. Indeed, the emerging countries are modelling their science, innovation, and intellectual property policies more and more along the lines of those of the developed countries and especially the United States – so as to be able compete in NST. Is this a good thing?

Our answer is both a “Yes” and a “No”. To explain this more, we first turn to Keynes, who noted that “The ideas of economists and political philosophers, both when they are right and when they are wrong, are more powerful than is commonly understood. Indeed the world is ruled by little else. Practical men, who believe themselves to be quite exempt from any intellectual influence, are usually the slaves of some defunct economist (Keynes, 1936)”.

The emulative policies of the emerging economies seem to be based on the standard economic theories of growth, both conventional macroeconomic growth theories, as well as the works of evolutionary theories that propose a clear line of policy intervention to create capabilities in a new science based sector. In the upstream segments of the supply chain, the government is to invest in the creation of scientific and technological capabilities in public and private laboratories. Thus, the State is held mainly responsible for the satisfaction of the creation of scientific capabilities (condition 1). Thereafter, the transformation of science into innovation, (conditions 2 and 3) is facilitated through supportive IPR and technology transfer policy as well as incentive-providing institutions. Finally, some economic actor has to pick up the bill, (condition 4). This could be the State, the innovating firms themselves or an active venture capital market. Over time, by a top-down percolation effect, it is assumed that the positive ripples will reach the low-income communities, and poverty will also be lowered.

The classic role of the State is thus three fold. It supports the building of scientific capabilities upstream. In downstream, final markets, the government protects citizens' interests and safety via regulation. Between supporting pure research and regulating the entry of innovations into the market, the State assists public laboratory and private sector endeavours through efficient institutions and policies. Moreover, policy seems to be guided by three implicit assumptions, which are also inspired by the catch-up trajectories of developed countries as well as different streams of economic thought. They are: (i) if the government invests more – the returns will be higher; (ii) if the IPR system is stronger, then the technological capabilities and innovation generation will improve; and (iii) if the venture capital market is sluggish, catch-up will be slower.

The first and second assumptions come from the standard theories of economic growth. And the third assumption is very often voiced commonly by all schools of thought. These assumptions are also embedded as beliefs in many of the practitioner community (scientists, firms and policy makers) given the reality of the differences between developed and developing countries. As players in the nanotechnology race, while both developed and emerging countries have jumped in to participate, they have started at substantially different times and the latter have far less resources to invest. It is therefore not a level playing field. After a decade of investment, as the introduction clearly pointed out, there is an enormous difference between the public investment of developed countries and those of emerging countries (barring China). There is also a very significant gap in terms of patent stocks indicating that the potential for commercializing new product innovations incorporating nanotechnology is also very asymmetric. These realities seem to be driving the emerging countries towards modelling their science, innovation, and intellectual property policies along the lines of those of the developed countries. However, the case studies in this book show that such emulation may not always be needed; nor may it be sufficient for catch-up in nanotechnology.

Given present realities, it is easy to suppose that were there more resources for the State to invest, emerging countries could build their knowledge bases, purchase equipment and develop scientific and technological capabilities. While this is of course true to a certain extent, catch-up theories of growth highlight that outcomes are not only dependent on the investments made but also the functioning of the national system of innovation (chapter on India). The rationale of the economic actors, their resources, skills and capabilities, their constraints, their information bases and the rules of the game which are set by the science, technology and innovation institutions are all crucial.

In all the countries studied, the State has been the financier of the construction of scientific capabilities. This has led to the creation of new institutions, training of students and the generation of scientific publications and patents. In all the emerging countries studied, the majority of the NST publications and patents have issued from public sector organizations.

Thus, it is not surprising, that public sector scientists especially cherish the 'more is better' assumption, claiming that their performance would improve if they had more funds. However, technology transfer to private firms is still on a low key and complaints about the governance of academic institutions voiced in most countries indicates that simply investing more without reform of the academic sector may not yield higher dividends.

IPR is assumed to be an important incentive for the transformation of science into innovation (conditions 2 and 3). In 1995, emerging countries by becoming members of the World Trade Organization, agreed to comply with the Trade Related Intellectual Property Rights (or TRIPS) convention. This meant that reengineering was no longer available as in the past as a catch-up strategy. At the same time, now emerging countries have their own version of the Bayh Dole Act; by providing the possibility for public sector researchers to patent, they have made it attractive to a greater variety of economic actors. How has this strengthening of IPR helped catch-up in nanotechnology? The answer is not clear. On the one hand, the fast development of Korea, Singapore and now China prove that TRIPS cannot be taken as a definite obstacle. On the other hand, new public research based products and processes are not spectacular in any country, even with the possibilities for patenting.

Many scholars consider the lack of an active venture capital system to be the greatest failure of emerging country innovation systems (Niosi, 2010). Indeed, no emerging country seems poised to have an active venture capital market even in the next half century. But, it is not clear if this is a major obstacle because in all the emerging countries studied, the State seems to be playing this role. The truth of the matter is that an active venture capital market seems to be an American entity, which cannot be replicated in the same effective fashion elsewhere, especially in emerging countries. Here, the less exciting substitute which seems to be serving the same function is government funding.

The case study of Solyndra in the USA provides further illustration of the limitation of the three truisms. It shows that even in the developed world, even when most stakeholders accept the proposition that more is better and the IPR is strong and the VCs are supportive – there can be failures. For instance, despite a competitive technology design, Solyndra lost its market advantage due to adverse changes in the innovation system, namely the entry of new (and foreign) firms with their innovations. In such cases, unless the State bails the original innovator out, or the other science and technology experts in the innovation system help in improving the technology design of the original innovator, the national firm can lose out. Venture capitalists, while being eager to finance the production of innovations that can yield high and relatively quick returns – are less apt to accompany the creation and commercialization of new low-priced essentials. Retention of secrecy under a strong IPR regime may not always be in the national interest. As was pointed out, economic growth and social welfare can be increased by reflecting and distinguishing between innovations for which the 'Social Innovation of Technology' route should be chosen. This is particularly noteworthy for emerging economies for which innovations that promote inclusive development are very important, given their higher poverty burdens.

By the same coin, even without funds pouring in from the central government or an IPR strategy or funding by VCs, interesting clusters can develop as illustrated by the chapter on Minatec in France through the efforts socio-techno entrepreneurs. This story proved that when change leaders mobilize active and intimate networks between a set of innovation stakeholders, who share common expectations of high rewards from cooperation and coordination, then a veritable technology cluster can be born. Factors such as history, legendary figures, inspiring leaders and inspiring organizations mixed with ‘drama’, ‘story telling’ and ‘historical glory’ can sometimes compensate for the absence of funds.

The above outcomes are not surprising. They have been observed in the biotechnology catch-up trajectories too. They show that in addition to ‘lack of funds’, an ‘IPR regime that prevents reengineering’ and the ‘absence of active VC market’, it is institutional inertia and flawed institutional designs in STI policy that are holding back emerging countries. There are missing resources, not only financial ones but also human resources, say in patent bureaucracies. There are missing institutions like active VC markets. There are missing capabilities, for instance, in the construction of instruments (which are still mostly imported) and in regulatory bodies. There are missing protocols, for example, in regulation of nanomaterials for environmental safety. The incentive systems are not able to attract many private firms to invest in incorporating nanotechnology into their production processes. On another note, in academic institutions, incentive systems are not sufficiently recognizing merit above social identities or social connections. Finally, it is worthwhile to recall one of the central lessons of the Latin American biotechnology experience, namely that it is impossible to develop and work upon a vision for sustainable development if there is high turnover of public servants and over interference of politicians with scientific establishments and public agency missions.

Where does this leave the emerging countries in the nanotechnology revolution? In the introduction, Susan Reid proposed three main possibilities for emerging countries with shallow pockets to catch-up. First, countries with weak financial, scientific and technological capabilities can aim for the low hanging fruit. Second, once they have developed strong scientific and technological capabilities they can identify and focus on niches. Third, after having acquired scientific, technological and financial capabilities, they can into jump onto building platforms. These can be platforms in terms of product focus say, tools, materials and devices or with a sector focus.

The first strategy is mobilized is pursued in all four countries, Brazil, China, India and Mexico, to construct original disruptive innovations, i.e. new designs of products, processes or business models whose quality and performance do not match their high-end counterparts, but which nevertheless create new markets or capture the market from rivals. The second strategy is viewed more positively in India. The third strategy is the target of China – albeit with State support from concept generation to product commercialisation. These outcomes make optimistic scenarios of rapid catching-up or technological leapfrogging in NST as evoked in other historical case studies highly unrealistic though not impossible.

To conclude, like in biotechnology, after more than a decade of deep investment, the pattern of acquired capabilities varies among the emerging economies. Currently, the entire set of non-high income countries account for less than 2% of patents in nanotechnology and this drops to less than 1% when China is removed from this set (introduction chapter). Moreover, as of now, it is not clear how this investment is contributing to economic growth or inclusive development in emerging countries. Thus, the main message of this book for policy makers in emerging countries is that given scarce resources, any ‘resource investment’ has to be constantly accompanied by ‘institutional reform’ to fit the evolving local context in order to be closer to the production possibility frontier of innovations. Echoing, Nelson (2008) an ‘accumulation of scientific and technological capabilities’ through investment in human and physical capital alone is not sufficient, for successful ‘assimilation’ of technologies requires effective institutions.

Our book presented many examples of how STI policy in emerging countries is contributing to catch-up in nanotechnology. China has undertaken a complete reform of its academic system and this is probably as responsible for its leadership position as the magnitude of its public investment. In Mexico, policy instruments such as the 'Sectoral funds' and 'Mixed funds' programmes are responding to problems within industrial sectors or regions, thereby exploring good fits between need or demand and State funding of science and technology generation. Brazil is taking a leadership in calling for South-South collaboration starting with initiative within Latin America. Brazil and India are both acknowledging that inclusive development with environmental sustainability should be a priority outcome of NST investment. Moreover, in India public laboratories are spinning out start-ups. To top it all, the commercial success of some disruptive innovations in India is generating more interest in nanotechnology among private sector firms than any government program. These confirm that while public investment and State policy are at the heart of a catch-up process, public investments alone will not yield desired outputs if the underlying set of institutional and social capabilities is inadequate and there are no sparks of interest in the private sector. Thus, even with the existing resources, with the State playing the role of the venture capital market, if emerging countries can address the challenges of missing or inefficient institutions, incentive systems and regulatory protocols, their national systems of innovation will be more effective in catering to their needs and aspirations.

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Table 1. The Increase in Biotechnology Publications in Latin America

Number of biotechnology articles by country and year, 1996-2008

Country	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008*	1996-2008*
Argentina	141	123	171	171	175	198	204	219	289	247	247	**2 436**
Brazil	292	349	454	469	540	656	661	755	1 077	1 164	1 106	**8 003**
Chile	55	78	63	68	77	88	90	112	134	121	123	**1 111**
Mexico	135	177	190	197	201	237	260	263	344	312	341	**2657**
PR China	818	1 014	1 110	1 411	1 646	2 179	2 751	4 318	5 652	6 732	6 368	**35 110**
Taiwan	316	285	347	372	371	491	519	573	765	755	736	**6 131**
Hong Kong	99	149	152	169	176	202	211	232	266	303	244	**2 384**
India	618	668	681	839	995	1 162	1 161	1 597	1 871	2 065	1 856	**14 532**
S. Korea	783	863	950	1 011	998	1 262	1 386	1 494	1 704	2 073	1 858	**15 661**
Singapore	65	87	121	121	137	202	232	288	336	367	354	**2 451**
World World	32 145	32 798	34 188	35 894	36 273	38 160	40 985	44 337	48 257	51 323	45 734	**503 047**

*2008 data are not yet complete
Source: Science-Metrix and Canada Research Chair on the Management of Technology.