Evolving a National System of Biotechnology Innovation
Some Evidence from Singapore

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Abstract

This paper attempts to look into the dynamics of National System of Biotechnology Innovation (NSBI) in the wider framework of its role in the economic development. It has been found that NSBI crucially depends not only on budgetary allocations and institutional support for advancement but also on response to the market demand. The evidence from Singapore shows that sectoral approach in NSBI may help developing countries in finding a niche for growth instead of broadening the area of investment within biotechnology. In case of Singapore, the bio-medical sector has been chosen by the national government for achieving desired growth rate in the manufacturing sector. The various components of NSBI and specific achievements of Singapore in this regard have been discussed in the paper.

Key Words: National Innovation System; Biotechnology; Contract Research; Singapore; Strategy for Growth of Developing Countries.

JEL Classification: O31; O33; O53.

Acronyms

BMSG	Biomedical Sciences Group
BMS	Biomedical Science Industry
BMERC	Biomedical Engineering Research Centre
BMS-IF	Biomedical Science Investment Fund
BMSI	BioMedical Science Investment
BIC	Bio-Informatics Centre
BTC	Bioprocessing Technology Centre
CROs	Contract Research Organisations
EDB	Economic Development Board
GIS	Genome Institute of Singapore
IMCB	Institute of Molecular and Cell Biology
INTECH	Initiatives in New Technologies Scheme
ITI	Information Technology Institute
ISS	Institute of System Science
IPRs	Intellectual Property Rights
JHS	Johns Hopkins Singapore
KRDL	Kent Ridge Digital Lab
MNCs	Multinational Companies
MD	Doctor of Medicine
MTI	Ministry of Trade and Industry
NIFA	National Innovation Framework for Action
NSBI	National System of Biotechnology Innovation
NICs	Newly Industrialised Countries
NIS	National Innovation System
NSTB	National Science and Technology Board
NSTP	National Science and Technology Plan
NUS	National University of Singapore
NTU	Nanyang Technological University
R&D	Research and Development
S&T	Science and Technology
SMEs	Small and Medium Firms
SSI	Sectoral System of Innovation
SPSB	Singapore Productivity and Standards Board
SGP	Singapore Genomics Programme
SBS	School of Biological Sciences
TNCs	Transnational Corporations
TIBS	Training in Biotechnology Scheme

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I Introduction

In the literature on National Innovation System (NIS), the role of country specific institutional framework in light of technological capabilities has been discussed at length. However, the analysis of innovation system in light of emerging sciences is a rather new phenomenon. Some of the papers such as Bartholomew (1997) and Senker (2001) have attempted to analyze such an innovation system for biotechnology. In these studies, efforts have been made to develop and define the contours for a National System of Biotechnology Innovation (NSBI). Incidentally, both the studies have a predominant focus on developed economies.

However, since the late nineties developing countries have also entered in biotechnology in an important way. Therefore NSBI for developing countries may help developing countries to draw policy insights from these experiences. It is also interesting to find that some of the developing countries are viewing biotechnology as a panacea for economic growth. Thus a large number of these countries are making strides in various sectors and are making efforts for development of this technology. One of the most aggressive of them is Singapore, where biotechnology industry is being promoted with a clear target of achieving 6 per cent economic growth through the manufacturing sector.[1]

Singapore has actually attempted to redefine national institutional context in light of developments in biotechnology. It has chosen a particular sector viz. bio-medical science for advance of biotechnology. Unlike its earlier technology policies, Singapore now supports public research institutions to a great extent. This signifies a major change in Singapore's approach towards S&T policy itself. It has already invested about US $20 billion in research and industrial parks as against US $15 billion by South Korea and US $13 billion by Taiwan.[2] The Singapore government has also promoted specific financial assistance schemes. The start-up companies from Singapore are now eligible for access to a US $ 20 million government fund set up exclusively to promote bio-industry.[3]

This paper is an attempt to look into the various components of NSBI in light of the current status of biotechnology in Singapore. The paper is organized in the following way. Section II attempts to develop an analytical framework for NSBI. Section III puts together broad science and technology policy related initiatives by the Singapore Government while Section IV tries to enumerate Singapore's attempts to find out a niche within biotechnology for expanding economic growth and exports. Section V deals with emerging demand of biotechnology goods and services in context of private sector participation in evolution of biotechnology in Singapore. The last section puts forth the broad conclusions from the paper.

II Framework for NSBI

The foundation pillars of NSBI have largely emanated from the dynamics of NIS, which has evolved, over a decade, as a conceptual research framework rather than a formal theory (Mani 2002). Instead of providing definite relationships between its variables, NIS suggests broad relations between various components (Nelson 1993). In NSBI, the integration of basic and applied research that is required for innovation takes place largely between firms and research institutions, rather than within firms only. Accordingly, biotechnology innovation may be conceptualized as the product of the accumulation of scientific knowledge in research institutions and firms (stock) and the diffusion of that knowledge between them (flow). The conceptual framework as developed by Bartholomew (1997) focuses on eight particular features of national institutional context, which affect these stocks and flows of scientific knowledge. They are tradition of scientific education; pattern of basic research funding; linkages with foreign research institutions; degree of commercial orientation of academia; labour mobility; venture capital system; national technology policy; and technological accumulation in related industries.

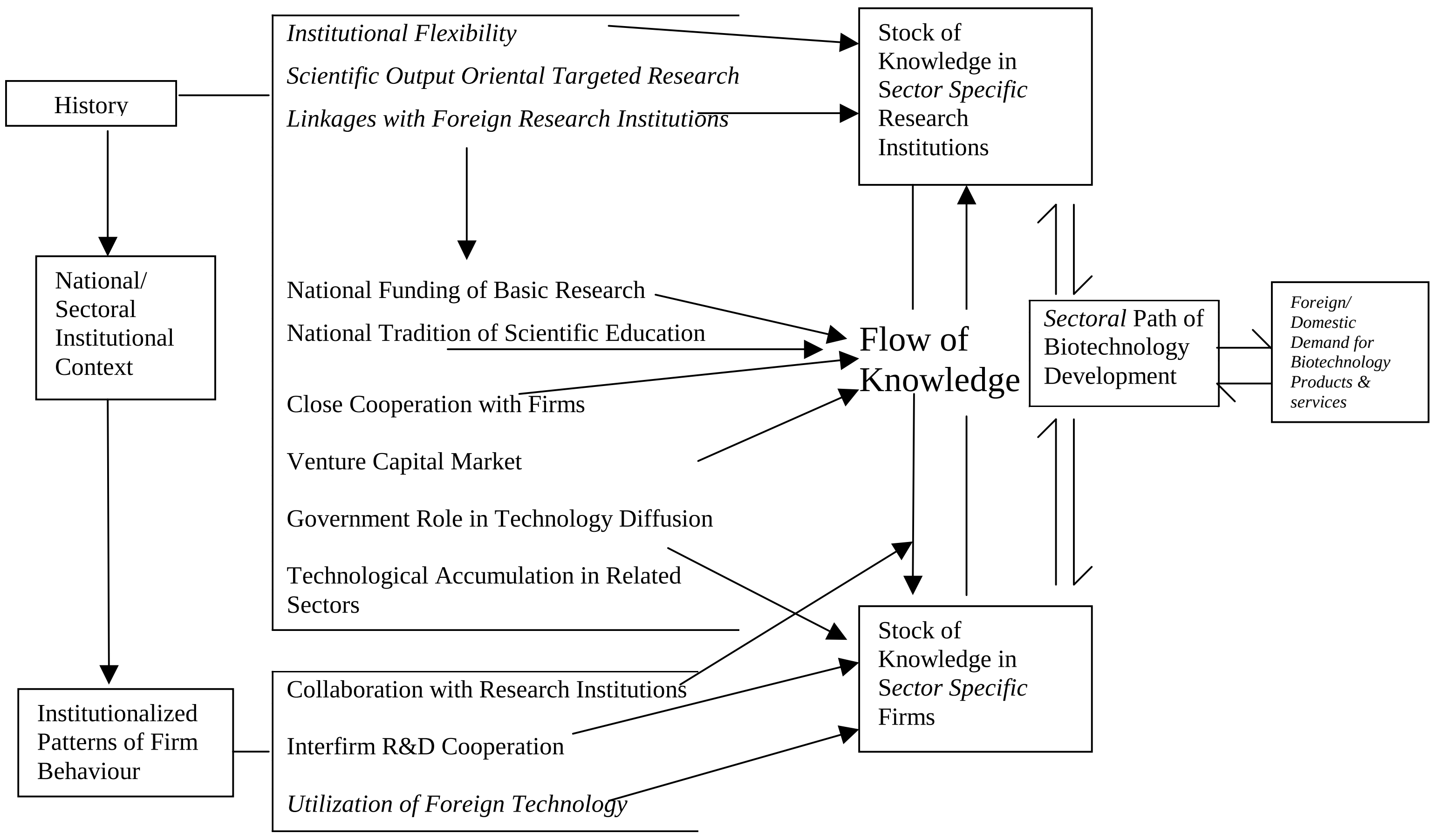
This model also considers three R&D practices at the level of the firm: collaboration with research institutions; inter-firm R&D cooperation and utilization of foreign technology.

However, in terms of desiderata for NSBI especially in the context of developing countries one may like to add a couple of additional components which may play an important role in the working of NSBI. Some of the developing countries may overcome the preconditions like the scientific traditions by resetting the institutional orientation towards science and technology. Apart from this the model for NSBI also need to consider the demand in the system and secondly the public acceptance of biotechnology products.[4] The policy support to encourage targeted research and ability to outsource R&D at firm and institutional level are other important constraints.[5]

It is important to realize that evolution of biotechnology in a particular science and technology system is also a function of demand for biotechnology related products. It also depends on the institutional dynamism within that system, which caters to the emerging demand of those products (Figure 1). As the system responds to the emerging demand this may even lead to sectoral specialization within biotechnology. NIS in case of developing countries is often found to be less developed in terms of institutional composition, the sophistication of scientific and technological activities and the linkages between organizational units.[6] Moreover, Shulin (1999) points out that for developing countries, as against developed ones, it is the capital, which plays key role in achieving technological excellence rather than knowledge and learning.[7]

Figure 1: National Systems of Biotechnology Innovation:

A Framework for Analysis



Source: Bartholomew, 1997 (italics added)

III Flow of Knowledge

The policy thrust at evolving domestic innovation system becomes clear from Singapore's National Innovation Framework for Action (NIFA)[8]. The NIFA document, prepared by Economic Development Board (EDB), National Science and Technology Board (NSTB) and Singapore Productivity and Standards Board (SPSB), aims to be a starting point from which an innovation roadmap for Singapore can be developed. The establishment of NSTB earlier was the first formalized effort by Singapore in the direction of developing NIS. One of the policy thrust in Singapore has been to firm up coordination between scientific infrastructure and industrial capability.

NSTB has been instrumental in launching three major five year plans on science and technology (Table 1). The Third Singapore Plan (2001-2005) classified technology development into three tiers. The first tier comprises the development, innovation/adaptation and acquisition of near term technologies. It called for deepening the technological capabilities of Singapore and engages in medium and longer-term technology development. The idea is to anchor the competitive position of its key industry clusters as well as to foster the growth of emerging high value-added clusters. Developing technologies in medium and long-term would equip Singapore with a continuous stream of innovative ideas and technologies which will support the development of future generations of products and services. The strategy is to be world-class in a few key technological areas with strengths in strategic areas of research, which demonstrates medium to long-term economic relevance. Such R&D efforts, it is proposed, are to be carried out in the research institutes/centres and universities.

Singapore has made efforts for promotion of sectoral innovation system. The S&T 2005 Plan is a clear example of that. It sets forth couple of key points: focus and strengthen R&D capabilities in niche areas; encourage private sector research and development in that field; establish a system for effective technology transfer and intellectual property management; recruit global talent and nurture local talent; develop strong international relationships and networks. The Plan document also proposed to set up two research councils, viz. the Biomedical Research Council and the Science & Engineering Research Council.

Table 1: S &T Plans in Singapore			
Five Year Plans	**Allocation S $ (billion)**	**Time Period**	**Objectives**
National Technology Plant (NTP)	2	1991-1995	Provision of grants and fiscal incentives to encourage more R&D by the private sector; developing and recruiting R&D manpower; support and funding for research institutes and centres that can train the manpower or provide the technological support to enable companies to undertake their R&D.
National Science and Technology Plan (NSTP)	4	1996-2000	Capability development in selected fields of advanced technologies.
Third Science and Technology Five Year Plan	7	2001-2005	Selection of strategic areas of research with medium and long term economic relevance.
Science and Technology 2005 Plan	-	-	Focus and strengthen R&D capabilities in niche areas; encourage private sector research and development; establish a system for effective technology transfer and intellectual property management; recruit global talent and nurture local talent; and develop strong international relationships and networks.
Source: Chaturvedi, Sachin (RIS 2002)			

There are certain important components of a policy regime which are essential for making NSBI work. They include arrangements like financial support; a clear strategy for supporting contract research organizations; open policy for imports of skilled manpower; promotion of close cooperation with firms and finally the arrangements for emergence of public attitude. In this section we would not get into details about public attitude as Singapore does not have any exhibited inclination for the agricultural biotechnology, against which public attitude has been strengthened in many countries.

III.1 National Funding of Basic Research

Singapore government has taken several measures to promote equity investments in commercial projects in biomedical sciences. Recognizing this, the EDB has allocated an additional US$ 600 million to attract leading international companies to conduct R&D through corporate research centres in Singapore. This was set aside as Biomedical Science Investment Fund (BMS-IF)[9]. The objective is to enhance industrial activities in Singapore by forming joint ventures, making venture investments in overseas companies with spin-offs to Singapore, or investing in local start-ups. The biomedical sciences industry attracted a record US $ 21 billion in the year 2000 worth of manufacturing fixed-asset investments commitment through 13 new projects. *Singapore Bio-Innovations* (SBI), a company funded by the Singaporean *Ministry of Trade and Industry*. SBI makes equity investment in foreign companies which have opted for alliances with Singaporean firms, for R&D, manufacturing, marketing and for distribution. There are also provisions for tax holidays and training grants. As a result, some foreign biotechnology companies plan to make Singapore a base for their Asian activities. Since its establishment in 1990, SBI has invested US$ 15 million in shares in 3 European 5 Asian and 15 US based companies. The European companies are largely from U.K. such as Oxford *GlycoSystems, Xenova LTD*, and *International Biotechnology Trust*. Some of the local companies in the SBI portfolio are *Aroma Biotech*, and *Plantek International*.

One of the several venture capital funds in Singapore dedicated to investments in the biomedical sciences industries is the BioMedical Sciences Investment (BMSI). This is part of EDB Investments Pvt. Ltd, which is the investment arm of the EDB. BMSI draws from direct equity investments in promising private companies worldwide, i.e. venture capital, co-investments with established players in Singapore-based joint ventures, investments in indigenous start-up companies and investments in established overseas biomedical sciences funds.

As of now, BMSI has in its portfolio over 50 companies globally. A number of these investments have resulted in research activities and clinical developments being undertaken along with the formation of joint ventures and start-ups in Singapore. In the year 2000, the government committed an additional S$1 billion (US$600 million) in the BMS-IF, bringing total investment funds under BMS's management to S$1.21 billion (approximately US$700 million).[10]

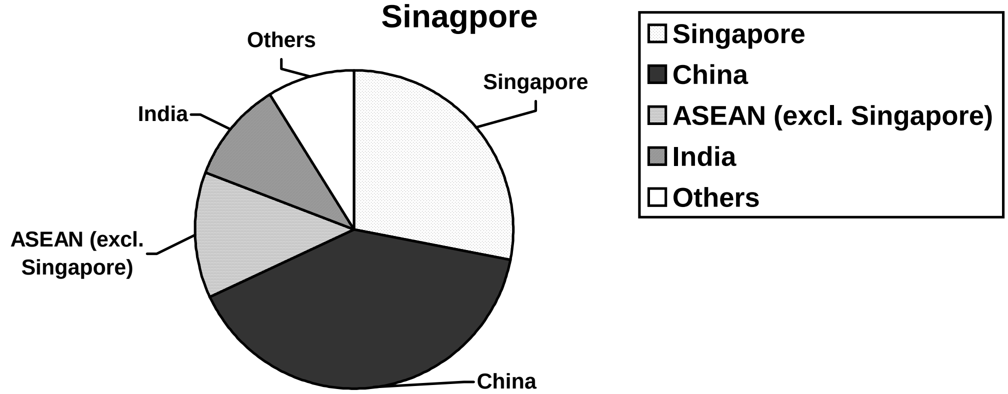
III.2 National Tradition of Scientific Education

Another important feature of NSBI is to strategize for overcoming the lack of scientific R&D traditions. The Singapore government decided to gear up the entire value addition chain to tap the potentials of growth in bio-medical sciences. This gradually led to building up of institutions addressed to specific excellence in pharmaceuticals and molecular biology research. The government also launched efforts to evolve Singapore as a major base for Contract Research Organizations (CROs). In Asia, Singapore has emerged as a major base for Contract Research Organizations (CROs). Singapore provides a rich database of patients with Indian, Malaya and Chinese origin to conduct such research. The size of Asian market is of $500 million and is expected to reach $800 million by 2004. While at the global level CRO industry size is of US $ 5 billion.[11] Some of the examples for instance are like Eli Lilly which has set up a joint venture clinical research centre in collaboration with the National University of Singapore in 1998. Another major group active in this field is Covance, which has set up a facility in Singapore. Covance had revenue of S$899 million. The group aims at getting 8-10 per cent of its revenue from the Asian region. Another major CRO is Quintiles Transnational. It is world's leading provider of information, technology and services to bring new medicines to patients faster and improve healthcare.

In light of limited domestic expertise in the filed of bio medical sector, Singapore has chosen an open policy to allow skilled manpower in this field. Research and educational institutes are working towards this objective. NUS and the NTU provide training at undergraduate and postgraduate levels. The research institutes, IMCB and the National University of Medical Institutes at postgraduate and post-doctoral levels, whilst the centres of competence contribute by providing project-based training in strategic fields. At the lower levels, Ngee Ann Polytechnic and Singapore polytechnic arrange 3-year diploma courses in biotechnology to train technical personnel for employment in the industry.

Singapore has also earned a distinct place as a centre for learning in biotechnology by establishing the IMCB in 1987 in NUS to develop and foster a vibrant research culture for biological and biomedical science to support development of biotechnology industry in Singapore. It has already produced 60 PhDs and a few hundred post-doctoral fellows and many summer students. The institute offers an integrated programme of advanced course work, laboratory research and seminars. Figure 2 shows the eminent position IMCB has acquired in terms of attracting students of different Asian origin.

Figure 2: Internationalization of Graduate Programs in Sinagpore



The NBP envisages manpower training at all levels. The NBP has also introduced the TIBS, to provide additional training in biotechnology by encouraging individuals from industry and academic institutions to attend short courses and engage in research attachments overseas. TIBS also supports developments in local infrastructure, which, in turn, facilitate technology transfer to Singapore. Other schemes include the Initiatives in New Technologies Scheme (INTECH) and the Research Exchange programme. A more recent example of how the university education follows closely with national agenda is the emphasis on biomedical sciences.[12]

III.3 Close Cooperation with Firms

The interfirm cooperation is a vital component of NSBI. Singapore government has encouraged the interfirm cooperation. Apart from financial assistance as mentioned earlier the Singapore government is also providing several sops to the firms so as to maximize their operations in Singapore. In this regard the EDB support has already started showing results. Recently, a research team from NUS, found a way of growing human embryonic stem cells that eliminate the risk of animal genes or diseases crossing over to humans. The breakthrough gives researchers an edge in the race to produce tissue and organs that can be transplanted into humans to help cure diseases.[13] There is a private company called ES Cell International, which is making efforts to commercialize stem cell research. This company is partly owned by the EDB and it is one of the few firms in the world that can supply stem cells to researchers. It is a joint collaboration between institutes in Australia, Israel and the Netherlands. The company holds six of the 64 stem-cell colonies that have been approved by the US for government funding. Human embryonic stem cells can transform into any cell in the body, so if scientists can control this, they can grow tissues and, eventually organs to replace diseased ones, or cure deadly diseases.

IV. Stock of Knowledge at Research Institutes

The mission of the NSTB is to encourage, develop and nurture human capital in scientific and engineering research and indigenous capability development for a knowledge-based economy in Singapore. The Singapore Government has been consistently enhancing the domestic allocations as part of a wider strategy to increase the domestic knowledge base of research institutions. International comparisons of GERD/GDP ratios in 1997 suggest that Singapore (1.39 per cent) compares unfavorably with South Korea (2.89 per cent), US (2.77 per cent), Germany (2.32 per cent) and Japan (2.91 per cent), but the observed gap is closing rapidly. It is with the Third five-year plan that the total national R&D expenditure has reached 2.09 per cent of GDP by 2001. As is clear from Table 2, the gross expenditure on R&D (GERD/GDP ratio) rose from 0.84 per cent in 1990 to 1.13 per cent in 1995 and 1.84 per cent in 1999. Singapore is aiming at a minimum 40 per cent private sector share of GERD and a target of 60 research scientists and engineers engaged in R&D per 10,000 labour force by 2002.[14]

Table 2: Singapore's Gross Expenditure on R&D			
Year	GERD (S$ million)	GDP (S$ million)	GERD/GDP ratio (%)
1978	37.80	17830.4	0.21
1981	81.00	31004.7	0.26
1984	214.30	40048.0	0.54
1987	374.70	43415.0	0.86
1990	571.70	67878.9	0.84
1991	756.80	75320.9	1.00
1992	949.50	80997.5	1.17
1993	998.20	94258.7	1.06
1994	1174.98	108224.0	1.09
1995	1366.55	120628.8	1.13
1996	1792.14	132629.3	1.35
1997	2104.00	141261.9	1.49
1998	2492.30	141216.2	1.76
1999	2656.40	143814.4	1.84
Source: NSTB (2001)			

IV.1 Institutional Flexibility

The NBP strengthened the technology capability in core areas by establishing centres of competence. However, Singapore has shown dynamism in overcoming institutional inertia by constantly monitoring the utility and contribution of research institutions in the light of broad economic goals of the country. This has enhanced the effectiveness and efficacy of NSBI. The urge for institutional innovation for international excellence saves the system from what is often called as 'institutional drag' and even 'institutional sclerosis'.[15]Institutional flexibility in the realm of biomedical and other related sectors has tremendously contributed to the emerging excellence in this field.

New courses are being introduced to suit the needs of the biomedical science venture. The Table 3 enumerates the attempts made in academics to match with the broader goals for economic development. It is evident that the courses being offered by the universities and other education institutions are tailored according to the economic priorities. For example, with the recent emphasis on biomedical sciences and technopreneurship, substantial increases in the number of new centres and courses offered by the universities to serve the needs of that nature are being set up. Similarly, the NTU will be establishing a School of Biological Sciences (SBS) and a Biosciences Research Centre. A third component, a Graduate School of Medicine, is being considered for Phase II to offer Doctor of Medicine (MD) Programme, modeled on problem-based solving and integrated learning approach in life science research, medical education and healthcare services.

Table 3: National Economic Priorities and Matching University Education Programmes

Year	Area of Development	University Developments	Key National Development
1999	Technopreneurship	NUS: A Minor Programme in Technopreneurship was introduced at the undergraduate and graduate levels. NUS: Another new course called Consulting Practicum for High Tech start-up that allowed students to undertake research/business strategy	The US $ 1 billion technopreneurship Investment Fund was launched to spur the development of the venture capital industry in Singapore.
1999-2000	Biomedical Sciences	NUS: New courses introduced in the year to train specialized manpower for the workforce such as: • Master in Pharmacy (Clinical Pharmacy); • Graduate Diploma in Psychotherapy • Graduate Diploma in Basic Ultrasonography * NTU: To establish $ 465 mill. College of Life Sciences	$ 62 million Singapore Genomics Programme (SGP) S 2 billion investments

Source: Development Bank of Japan, August 2001

Some attempts are also being made for streamlining institutional infrastructure as it may affect all cognitive processes. Recently, government decided to close down a research institute working on agricultural biotechnology as Singapore does not have very high stakes in the agricultural sector, but later considered the MTI proposal to work towards the merger of the Institute of Molecular & Cell Biology (IMCB) and the Institute of Molecular Agrobiology.

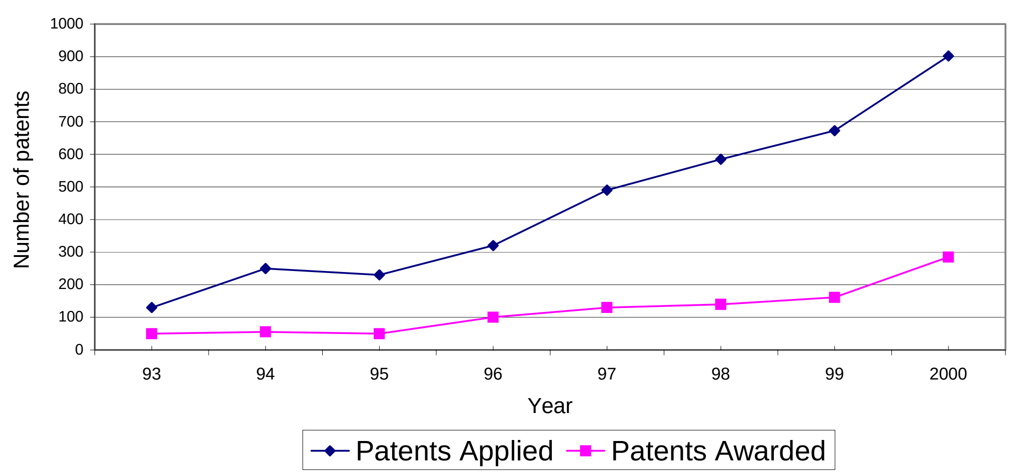
The proposal has already been approved by the Life Sciences Ministerial Committee. Similarly, in 1998 Kent Ridge Digital Lab (KRDL) was formed through a merger of the ITI and the ISS. It is mostly funded by NSTB – around 65 per cent – and the rest comes from other sources. KRDL quickly established itself as one of the most dynamic software labs in Asia. In this short span of two and a half years, its 10 spin-offs founded by its staff utilising KRDL technologies. The company has specialised in IT infrastructures for life sciences and knowledge-based solutions for enterprises in medical imaging and bio-informatics systems.

IV. 2. Scientific Output Oriented Targeted Research

To encourage development of technological capability, Singapore has enacted a new patent law with effect from 1995. There are some fairly elaborate transitional provisions. Furthermore, until a cadre of Examiners has been established in Singapore, Examiners at the Australian Patent Office will in fact carry out examination. Principal features of the new law cover a similar definition of protractible subject matter as that of the European Patent Convention. The law proposes that the novelty will be assessed on a worldwide basis having regard to both publication and use. Furthermore the whole contents of any prior-filed Singapore application will be destructive of novelty of an application having a later filing or (where relevant) with any prior date. The term of a Singapore patent is for 20 years from the filing date. Maintenance fees will be payable on the fourth and subsequent anniversaries of the filing date. A number of options regarding examination are provided including a request for local search and examination. Presumably there will be fees in connection with both requests. Examination must be requested within 22 months of the priority date.

The impact of this growing emphasis on domestic R&D is evident from the patenting activities as well. The number of patents applied for in 902 in the year 2000, up by 34 per cent from 1999, while the number of patents awarded grew to 285, up by 77 per cent from a year ago in 1998 (Figure 3). This shows the increased awareness, by both private and public sector on the need to protect their intellectual properties arising from their research activities.

Fig. 3: Number of patents applied and awarded from 1993-2000



IV.3. Linkage with Foreign Research Institutes

At the leading research centres like IMCB, the pressure for international publications has gone up several times. Scientists have published over 800 research papers in top international journals and filed several patents. IMCB has also facilitated the growth of International Molecular Biology Network for Asia and Pacific Rim, which has participation from Japan, China, South Korea, Hong Kong, Taiwan, Malaysia, Thailand, Indonesia, Australia, New Zealand and Israel. The network has been established on the lines of European Molecular Biology Organisation, and is a significant co-ordinating organisation for the life sciences in Europe. One of the important projects at IMCB involves the sequencing the genome of the puffer fish (commonly known as fugu). This represents a huge step forward for the worldwide human genome project. Joining in the collaborative effort to sequence the fugu genome are 500 to 600 researchers from the UK based Human Genome Mapping Resource Center; the Molecular Sciences Institute in Berkeley, California; and the Institute for Systems Biology in Seattle. The impact of this project would be huge in terms of helping derive the advantages of the human genome, which has been nearly sequenced.

Actually now a pyramidal institutional structure for life sciences has emerged in Singapore with NUS and NTU at its base providing critical support to IMCB, which is now at the peak of this pyramid. KRDL and John Hopkins Singapore are other major institutions on the biomedical institutional map of Singapore. In 1998 itself the Johns Hopkins University also established Johns Hopkins Singapore (JHS) as a base for medical operations in Southeast Asia. JHS works hand-in-hand with other Singapore medical institutions and organisations to perform world-class research in biomedical science in various diseases endemic to Asia, with the hope of developing new therapies and diagnoses.

V Stock of Knowledge at Firms

Singapore has carefully carved out areas to promote and develop industry-driven R&D in Singapore. For this it provides grants and fiscal incentives to encourage more R&D by the private sector; develop and recruit R&D manpower; support and fund research institutes and centres that can train the manpower or provide the technological support to enable companies to undertake their R&D and provide commercialization and infrastructural support. In the First National Technology Plan (NTP) the budget was of S$2 billion which become S$4 billion in the Second Plan.

The strategies and policies for developing the biomedical sciences industry, conceptualised by the EDB's Biomedical Sciences Group (BMSG), is to build Singapore into a World-Class Hub for Biomedical Sciences, with capabilities across the entire value chain-from research to manufacturing and housing regional headquarters of major companies. This priority plan gets very well with the empirical results available from different studies have shown that the degree of internationalisation of R&D is positively associated with pharmaceuticals sector.[16] Thus, TNCs in this sector choosing Singapore for investment is very much on the expected lines. The BMSG provides assistance to TNC entrants that are considering Singapore as a location for investments in R&D, manufacturing or headquarter services by linking them with suitable local research organisations, industrial land/facilities agencies and other supporting services.

At the same time, the BMSG nurtures the growth of local start-ups and other major companies. It focuses on three strategic thrusts in its efforts to make Singapore a global focal point for Biomedical Sciences activities: human capital, intellectual capital and industrial capital development. Table 4 shows that in the year 2000 the manufacturing output of biomedical science industry (BMS) grew by 2.1 per cent to S$6.4 billion and its value added grew by 2.7 per cent to S$5.2 billion. The share of BMS in the total manufacturing output grew from 4.64 per cent in 1999 to 4.76 percent in the year 2000, which in value terms was S$130 million. Similarly, share of BMS in manufacturing value added sectors grew from 15 per cent to 19 per cent during the same period. The share of BMS in direct exports in 1999 was $709 thousands, which was almost 9 per cent of total manufacturing exports. One of the aims of the EDB is to house 15 world-class companies, and a regional centre for clinical trials and drug development by year 2010 at Singapore.

Table 4: Share of BioMedical Science (BMS) Industry in Manufacturing Sector of Singapore

	2000			**1999**		
	Manufacturing Sector	**BMS**	**Share (%)**	**Manufacturing Sector**	**BMS**	**Share (%)**
Employment (No)	338,885	5300	1.56	338,885	5600	1.65
Output (S$M)	130.24	6.4*	4.76	133.57	6.2	4.64
Value Added (S$M)	27.52	5.2*	18.53	34.92	5.2	14.89
Establishment	-	-	-	3928	36	0.9
Workers	-	-	-	338885	5312	1.6
Direct Exports ($000)	-	-	-	85359764	709	8.31

Source*:* Industry Statistics, Economic Development Board (2001b), Singapore.
Note: * Figures are in billion.

The industry capabilities would go up several times once the proposed taskforce is set up to look into the establishment of a Biomedical Grid that will facilitate the sharing of data and computing resources, enhancing collaboration and co-operation among biomedical research organisations in Singapore. The proposed Grid is a sophisticated IT infrastructure facility that will enable biomedical information to be shared and distributed along a secure data network linking high performance computing resources.

V.1 Interfirm R&D Cooperation

Apart from the factors enlisted the NSBI has another important determinant, namely the demand for various biotechnology products and services. The Singapore economy has created an important position for advance technology goods. This growing demand has strengthened the supply chain up to the level of innovation in a major way. Singapore aims to be the home of 15 world-class biomedical sciences companies and to become the region's centre for clinical trials and drug development. Aventis, GlaxoSmithKline, Merck, Schering-Plough, Pfizer, Wyeth-Ayerst, Baxter and Becton Dickinson are some of the world-class companies that have established global manufacturing plants in Singapore[17]. Table 5 provides a detailed list of major investors in BMS in Singapore. Some of them like S*Bio are major domestic players. Though investment figures for all the companies are not readily available, the table does refer to their area of working. Figure 4 gives further break-up of the activities of these companies especially in light of their R&D endeavours. Actually several of the EDB initiatives are evident from Table 6, which shows the relative share of TNCs and domestic companies in R&D in Singapore. In case of life sciences, domestic companies have a share of 63 per cent in the total private sector R&D expenditure in Singapore which is very close or in some cases even higher than their share over well established older industries in Singapore like engineering (45 per cent) and electronics (67 per cent).

Table 5: BMS in Singapore: Investments and Objectives of Major Companies

S.No	Company	Investment	Purpose
1	Pfizer (US)	S$600 million	Chemical bulk active plant
2	Schering-plough (US)	S$630 million	Chemical bulk active plant; A secondary manufacturing plant and a chemical process R&D center; A chemical process R&D center
3	Aventis (France & Germany)	$60 million	Pharmaceutical bulk-actives facility
4	Wyeth-Ayerst (US)	$250 million	Hormone replacement therapy product
5	Mallinckrodt (US)	US$2.6 billion	Healthcare company in respiratory care; Diagnostic imaging and analgesic pharmaceuticals
6	Schering-plough (US)	S$170 million	Biological Drugs
7	Schering-plough (US)	$170 million	Additional plant to produce biological drugs
8	Hoffman-La Roche Ltd (Switzerland)	-	Regional Diagonostics Centre known as Roche Diagnostics Systems Regional Centre
9	Smithkline Beechhan (UK), now GlaxoSmithkline	-	Asia Pacific clinical research and development headquarters
10	Merck, Sharp & Dohme (MSD) (US)	-	Bulk chemical plant

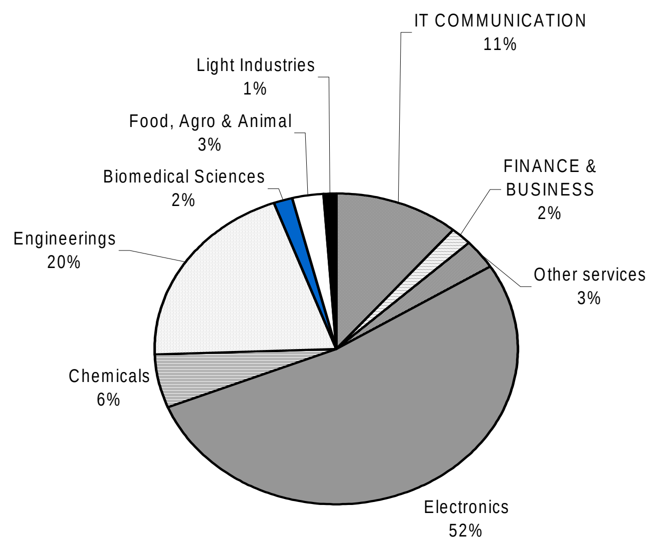
11	Applied Biosystems (US)	-	Fully Automated Polymerase Chain Reaction Machines
12	3M (US)	-	Innovation Centre
13	Siemens Medical Instruments (Germany)	-	Manufacturing and logistics for its hearing aids business
14	Sysmex Corporation (Japan)	-	Hematology analyzers
15	Becton Dickinson (US)	-	Asia Pacific R&D Centre
16	PE Corp (US)	-	Investments to enhance the capabilities of R&D and manufacturing capabilities
17	Biosensors (SG)	-	A locally minimally invasive surgical company has gone into the research of developing its own stents for people with cardiovascular diseases. This is one of the more innovative local manufacturing capabilities.
18	S*BIO (SG)	-	Fully integrated drug discovery company
19	Optimer (US)	-	Proprietary technologies to discover carbohydrate-based drugs for Cancer and infectious diseases
20	ES Cell International (SG)	-	Develops and commercialize human embryonic stem cell technologies
21	Cell Transplants (US)	-	Pilot production facility
22	Oculex Asia Pharmaceuticals (US)	-	Post-cataract inflammation treatment
23	Covance (US)	-	Central laboratory to provide clinical trial testing; Data management and drug distribution service
24	International Medical Centre	-	To provide high quality patient care, initially in the field of Oncology; Conduct cutting-edge research in drug development; Clinical education programs and degrees, in conjunction with NUH and NUS
25	ReasonEdge Techologies (US)	-	To develop advanced decision analysis toolkits for knowledge management; Business intelligence in the healthcare and pharmaceutical industries
26	Pharmacia & Upjohn	-	40-man Asia Pacific Clinical Development Centre
27	Schering-Plough Research Institute (US)	-	Clinical Research Centre in Science Park II
28	Parkway Group (SG)	-	Gleneagles Clinical Research Centre

Table 6: Foreign Companies' Share of Industry R&D Expenditure, 1997

Industry Group	(1) Foreign majority owned companies ($mn)	(2) Local majority owned companies ($mn)	(3) Total R&D Spending by Industry ($mn)	(1) (3) %
MANUFACTURING	**727.24**	382.85	1110.09	65.51
Electronics	424.25	201.59	625.84	67.79
Chemicals	168.54	34.09	202.63	83.18
Engineering	94.78	113.92	208.70	45.41
Precision Engineering	74.62	74.2	148.82	50.14
Process Engineering	7.77	4.33	12.10	64.21
Transport Engineering	12.39	35.39	47.78	25.93
Life sciences	36.81	21.53	58.34	63.10
Light Industries/Other Manufacturing	2.86	11.72	14.58	19.62
SERVICES	76.60	127.84	204.44	37.47
IT and Communications	47.69	86.85	134.54	35.45
Finance & Business	12.61	15.8	28.41	44.39
Other Services	16.30	25.19	41.49	39.29

ALL INDUSTRY GROUPS	803.84	510.69	1314.52	61.15
Source: 1997 National Survey of R&D in Singapore, National Science & Technology Board				

Figure 4: Breakdown of Private Sector's GERD by Industry Clusters



V.2 Utilization of Foreign Technology

As an outcome of adoption of new technologies in the pharmaceutical research and an ongoing race for related IPRs, firms have been exploring options for reducing time lag in drug development. Pharmaceutical companies have started outsourcing discovery research and development. The development part itself has several stages including pre-clinical and clinical testing. Apart from this, the drug companies have realised that ethnic sensitivity and profile of endemic diseases have also to be looked into before the drugs are finalised for the region. As a result, several Contract Research Organisations (CROs) have come up at the global level. These centres provide healthcare support services in terms of full clinical trials, including a full spectrum of product development and commercialization. Thus, these companies or centres take over from where pharmaceutical or biotechnology companies leave the chain of product development. As the US, Japanese, and European firms move on to focus more specifically on drug development and genetic R&D, more CRO work is likely to be generated. On average, about 30 per cent of worldwide R&D expenditure on clinical development are outsourced to CROs.[18] Worldwide CRO has grown into a US$5 billion industry. The market for contract drug development market is expected to grow at approximately 18 per cent per year over the next few years. R&D efforts in life sciences would further grow with the excitement of the impending completion of the human genome project. Singapore has established itself as a major CRO in the Asian region. The market turnover of CRO activity in Asia is close to $ 500 million.[19]

VI Summing up

It is clear that Singapore now has a new approach towards NIS. It involves not only a pro-active agenda for R&D programmes but also facilitates successful emergence of a domestic commercial sector. Bartholomew (1997) has discussed important components of NSBI viz. R&D system, role of public sector and public policy, international relations, internal organization of firms, their relations with other firms, education system and finally set up of the financial system. The evidence from Singapore reflects on some of the other important determinants for NSBI.

The evidence shows that some economies may exhibit preference for path dependency model when it comes to sectoral specialization in a cost intensive frontier technology like biotechnology. The institutional emphasis on biomedical sector in Singapore is a case in point. The detailed study of biomedical sector in Singapore shows that government's response in meeting the emerging demand pattern and related emphasis on domestic capability building shows that in a frontier technology, sectoral focus of innovation system is equally relevant and useful in explaining the dynamics of economic growth.

This sector specific institutional set up and the structure of production influence the innovation performance of firms to a great extent. The R&D institutions in the biomedical sector are being encouraged in Singapore for manpower development. Liberal budgetary allocations are being made for their programmes. The EDB and NSTB are acting as major forces guiding the growth of a frontier technology to the advantage of each of the constituent of the manufacturing sector, viz. electronics, ICT, medical and diagnostics sector. This is a novel experiment in the development of a new technology tapping it for growth and development of a country, which is oriented towards the world market. EDB encouraged foreign investors for positive spillovers through fiscal measures like grants and tax incentives and at the same time made efforts for enhancing the domestic pool of skilled manpower. The liberal policy of allowing foreign universities and research institutes is also to facilitate technical upgradation of manpower skills and import of talented scientist and engineers. Almost seven foreign universities have opened their branches in Singapore. In both these cases, the medium and long-term expectation is that these skills learned in foreign countries would be transferred to Singapore. At IMCB, there is a great pressure to increase Singapore's share in international papers and citations. This shows how effective national system of biotechnology innovation may become in terms of bringing together national science base and domestic firms. The timing of these two measures is extremely important. The growth of biotechnology sector in Singapore shows that these measures would be most efficacious if time gap between them is minimal. Such measures may make TNCs transcend national boundaries.

The sectoral approach of NSBI has also brought a change in the concentration of industry, as seen earlier. Now the industrial locations in Singapore are accompanied with and linked to a major university or a research facility. This may play an important role in industrial development. This may also help in improving the domestic science base and ultimately would enhance its utility for domestic emerging start-up firms in this sector. It has also become clearer that the environment within which NSBI operates is also important. At times, demand plays as much a stronger stimulator for innovation than any other factor. It also has to be acknowledged that there are limitations to the success of leverage strategies, widely adopted by almost all the NICs[20]. Whereas the semiconductor industry, electronics and IT are characterized by many competitors, fast product life cycles and higher assimilation probability are not true with an industry like biotechnology.

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Endnotes

Singapore's economic transformation has primarily been driven by its twin engines of growth – manufacturing and finance & business science.

[2] Mitchell (2000).

[3] Mitchell (2000).

[4] Senker (2001)

[5] Chaturvedi (2002)

[6] Shulin (1999).

[7] NICs like South Korea and Taiwan used advanced technologies along with sophisticated managerial skills for successful catching up (Kim (1997) and Stiglitz (1996).

[8] This was adopted on January 1998.

[9] Lee (2001)

[10] EDB (2001a)

[11] McManus et al. (2001)

[12] DBJ (2001)

[13] The Strait Times, 21st September 2001.

[14] DBJ Report (2000;2001)

[15] Johnson (1992) p. 23.

[16] Patel & Pavitt (1998)

[17] Lee (2001)

[18] Far Eastern Review, February 8, 2001

[19] Far Eastern Review, February 8, 2001

[20] Mathews 2001