

From “Silicon Island” to “Biopolis of Asia”: INNOVATION POLICY AND SHIFTING COMPETITIVE STRATEGY IN SINGAPORE

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Because of Singapore’s ability to create a thriving semiconductor and electronics industrial cluster through leveraging multinational corporations, noted industry and innovation analyst John Mathews aptly described it as a “Silicon Island of the East.”¹ For those interested in innovation policy and national strategy for transforming the industrial landscapes of developmental states, Singapore’s unique mix of state planning with capitalism has always been an interesting case to ponder. Although Singapore has graduated into the ranks of “developed” industrial states, it now faces new challenges and opportunities due to rapid technological change and economic globalization. In retrospect, industrial planners in developmental states such as Singapore believe that they had followed the “right” innovation policies to spur economic growth, despite the fact that all policy prescriptions are subject to uncertainty at the time of their implementation. It has long been recognized that uncertainty pervades innovation; how firms and associated agents of technological change manage uncertainty shapes the competitiveness of nations.² However, the innovation strategies being pursued in recent years by countries in Asia and elsewhere represent a fundamental shift in the way governments approach economic stimulation.

This article analyzes the recent changes in Singapore’s innovation strategies using the national innovation system (NIS) framework. NIS is a techno-economic paradigm that has become an important analytical tool to study national competitiveness, technological change, and innovation policies. A

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systemic approach captures the dynamic and evolutionary nature of innovation, which in turn recognizes the contingent and emergent nature of technology development.³

Singapore's post-colonial industrialization and economic growth strategies were consistent with Porter's claim that states are still important actors in enhancing innovation, technological learning, and national competitiveness. As he puts it, "In a world of increasingly global competition, nations have become more, not less, important."⁴ The competitiveness of Singapore's economy, despite occasional cyclical downturns, was based on its ability to innovate and learn production and process skills and to leverage MNCs in key industrial clusters.⁵ In the changing international innovation milieu, states must delicately balance national economic interests without compromising the needs of their innovation partners to have more freedom and maneuverability to attain the common goal of competitiveness and national comparative advantage.

A clear indication of such a radical strategy has been Singapore's ambitious and potentially risky mission to create a biotech industrial cluster. A new mode of innovation has been evolving in the research-intensive biomedical industries cluster, which emphasizes a special role for the academic sector in the innovation milieu. This evolving innovation structure resembles the "triple helix" framework, which is a stylized variant of the NIS model, with the former gaining salience with the progress of the knowledge-based economy.⁶ In the case of Singapore, the NIS framework applies to the traditional three pillars of the local industry—electronics, precision engineering, and chemicals—while the triple helix is more amenable to the biomedical cluster. While the NIS stresses the co-evolution of state and industry in a double helical mode with the state in control of industrial and innovation policies, in the triple helix framework, industries and universities are given more space and say in the evolving innovation policies and competition strategies. This is in line with the finding that the rapid pace of globalization and the pervasiveness of information and communications technologies have signaled the evolution of a more interactive and network mode of innovation.

Recent government actions show that in order to maintain competitiveness and economic growth, Singapore is moving away from an exclusive dependence on investment-driven (mostly FDI) industrialization to more knowledge- and research-intensive industrialization that follows a horizontal and network mode of innovation by nurturing start-ups and small- and medium-size enterprises (SMEs) and also by attracting biotech MNCs. The objective is to boost public and private investment in higher education and research to transform Singapore into an important hub of biomedical R&D, drug discovery, genetic medicine, pharmaceutical production, and health services.

The point of departure for the present analysis is the industrial and technological development policies that Singapore had pursued up until 2000.⁷

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Path-dependency analysis is not always sufficient to delineate and predict innovation trajectories; nor are innovation trajectories entirely random phenomena.⁸ Internal as well as external political and economic factors play critical roles in shaping the modes of innovation and economic growth patterns of all countries.

Biotech investments at the moment face high risk due to the rather amorphous and unclear market signals coming out of the industry. Therefore, pursuing the most appropriate innovation policies and competition strategies is crucial for Singapore to maintain its economic fortunes in a difficult region and a volatile global economic environment. It must adopt the policy changes needed to create a “national innovative capacity”⁹ by embracing a horizontal innovation mode to propel itself into the so-called “knowledge-based economy.”

Industrialization and Economic Development in Singapore

Since gaining self-rule in 1959 and full independence in 1965, Singapore has made a remarkable transition from a Third World to a First World economy.¹⁰ This transition was attained by an average annual growth rate in real GDP of about 8.7 percent from independence until 2000.¹¹ Singapore’s per capita income was US\$20,700 in 2001, placing it on par with such OECD countries as France and Germany.¹² Singapore’s rapid economic growth was achieved through “continuous industrial restructuring and upgrading.”¹³ Singapore’s early industrial success was attributed to its ability to be a low-cost and efficient manufacturing base for U.S., European, and Japanese MNCs. Singapore’s economic development was attributed to its single-minded concentration on labor-intensive manufacturing in the first decade after independence and sustained excellence in manufacturing attained during the subsequent two decades by continuously upgrading its technological capabilities.¹⁴ Economic growth was also fueled by the continuous expansion of the service sector—transportation, logistics, telecom, and tourist services—through rapid technology uptake and infrastructural development.¹⁵

Singapore’s technology-intensive industrial development was facilitated and guided by a paternalistic developmental state.¹⁶ In fact, Singapore’s economic growth through high value-added manufacturing exports is attributed to its “unique cocktail of state planning and capitalism.”¹⁷ However, unlike Korea and Taiwan, high-technology manufacturing industries were not indigenously developed. Singapore’s rapid technological development—particularly in electronics, semiconductor, data-storage device, chemical, and precision engineering industrial sectors—was largely dependent on foreign direct investment by MNCs.¹⁸ Singapore attracted MNCs by leveraging on its locational advantages as a low-cost and high-volume manufacturing center of electronics goods.¹⁹ Singapore, like other East Asian latecomer cohorts, adopted technology leveraging as its industrial development strategy.²⁰ By leveraging the technologies transferred by MNCs during the earlier stages, and subsequently expanding R&D investments in high-technology industrial ventures, Singapore has considerably

expanded its technological knowledge base. Having exhausted the potential gains from technology upgrading and acquisition through export-led industrial development strategy, Singapore now claims that it has embarked on a different trajectory of technological innovation by recreating itself as a “learning nation” that could become a leader rather than a follower.²¹ The emphasis has shifted from value-adding services as the strategy for economic growth to nurturing value-creating industries through high-tech innovation to enhancing national competitiveness and economic growth.

The earlier stage of Singapore’s industrialization followed a version of the NIS mode applicable to small resource-poor developing nations. In such cases, the emphasis was not on R&D-based innovation and new-to-the-market product development, but on creatively leveraging the technology transferred to the state by foreign MNCs as the mechanism for enhancing industrial capability. Singapore’s government took the initiative through building appropriate national institutions and policy instruments, the essential foundation of the NIS,²² to guide and regulate the direction of innovation and industrialization as part of a nation-building strategy. NIS is essentially a set of institutions that generate and mold economic growth in which technological innovation is the key driving force.²³ According to Freeman, NIS is the “network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies.”²⁴

In this model of innovation, the government takes an active role in formulating industrial and technology policies. The emphasis is on national-level institutions, specifically the national government and its relevant ministries and departments along with firms, local as well as foreign. The term national is meant in the sense that at least some deliberate policy strictures are proposed by the governments at the national level to spur technological innovation.²⁵

However, the third sector of the NIS—academia—does not play a significant role in inducing innovation. It plays only a subsidiary role as providing basic discipline-based education and training for engineers, scientists, and managers. Any R&D work is confined within industries to solve narrowly defined problems to increase productivity and create process technologies.

A caveat is in order regarding the applicability of NIS to Singapore. As Nelson and Freeman concede, there is no clear algorithm as to how the NIS model could be applied to the case of individual countries as their historical experiences differ and they stand at different stages of economic and industrial development. Wong argues that the NIS framework could be applied to Singapore if we adopt an “explicit dynamic system perspective” as opposed to the static nature of the model conceived in a path-dependent manner.²⁶ Wong’s approach is, however, not different from the general NIS framework because he also looks at the primary institutional actors—firms, public agencies responsible for industrialization policy, and manpower development and training institutions—as the key agents that work together with the government acting as the leader.²⁷

The most important agency within the Singapore Government that played a crucial role in Singapore's economic growth through rapid industrialization was the Economic Development Board (EDB), a pre-independence era body that was set up in 1961.²⁸ The EDB took over the crucial role of preparing the groundwork for industrialization of the city-state, which until that period had no meaningful technology-based manufacturing industry. The colonial administration had used Singapore only for entrepôt services, for bringing Western manufactured goods to sell to the region, and for exporting the produce from the region to the West.²⁹ With a large and restless workforce available at comparatively low wages, the EDB tried to woo foreign MNCs looking for low factor-cost locations to set up manufacturing plants in Singapore. The Jurong Town Corporation (JTC) was formed to manage and provide land and industrial space for the MNCs in the land-scarce city-state. Public Utilities Board and Housing Boards were also created for providing reliable and cheap electricity, water, gas, and housing needed for the industrial estates. The Development Bank of Singapore (DBS) was established to provide the financing for industrial development. Legislation was also introduced to tame the militancy of the labor unions.³⁰

Within three decades, Singapore has transformed itself from being a poor developing country devoid of virtually any technological capability to a modern industrialized nation with strong technological capability in several key high-tech industry clusters. However, recent structural changes in the regional and global economies have exposed Singapore's vulnerability as a predominantly value-adding manufacturing base dependent on export-led development as its passport to economic growth. Singapore's industrial expansion and economic growth was put to severe test after the 1997 financial crisis. As a result of the contingencies thrown up by the financial crisis and in line with Singapore's slow emergence as a "post-industrial"³¹ economy in the late 1990s and at the turn of the twenty-first century, one could notice the beginning of a new innovation system emerging in Singapore with greater interactive dynamics between the state, industry, and academia. The rudimentary stage of this triple helix mode of innovation could be linked to the "technopreneurial" development scheme as well as the "Industry 21" campaign initiated by the EDB in 1999. The Technopreneurship 21 (T21) program was put in place with the Technopreneur Investment Incentive (TII) Scheme as the cornerstone of nurturing innovation and start-up activities "in spirit and style to the Silicon Valley model."³² Through its "Industry 21" campaign, EDB plans to make Singapore a globally competitive "knowledge-based" economy. Singapore is now bent on entering the global high-tech market as an important player that is not only good at adding value, but also at creating the value chain itself by forging new industries in knowledge-based innovation and technology development. The emerging innovation system in the research- and knowledge-intensive sectors in Singapore needs an epistemologically oriented framework (such as the triple helix of government-industry-university interactive system) to understand its dynamics.

Reconfiguration of University-Industry-Government Relations

The triple helix system, in the case of Singapore, is still very much a variant of the NIS mode, but the nature of the interaction between the three actors has changed to reflect the new realities of globalization. The variation is reflected in the dynamics of interaction between the core agents.³³ The evolution of a new trajectory of innovation systems in Singapore is in many respects a serious response on the part of the government to address the consequences of the Asian financial crisis of 1997-98 as well as the impact of globalization and the bursting of the dot-com bubble. Singapore's GDP shrank by 2.4 percent in 2001; the worst recession the country had experienced since independence. As a result, the Singapore Government has undertaken a serious revamping of its industrial and economic policies. The government has implemented pro-active policies to revive economic growth and wealth creation through Silicon-Valley-style innovation and knowledge management practices and competition strategies. The objective is to reinvent Singapore as a "learning nation" such that the "spirit of innovation" would "permeate every level and sphere" of society.³⁴

The Asian financial crisis exposed Singapore's economy to the dangers of being dependent on the Southeast Asian region for its growth. To insulate Singapore's economy from such vulnerability, the government is looking outside than the region to improve its economic fortunes. The government's strategy is to become a serious player in the global high-technology markets, particularly in the biotech market. In order to reach this goal, Singapore firms needed to be competitive in the international technology markets dominated by North American, Japanese, and EU firms. The strategy for Singapore and its firms is to follow certain strategic technology sectors as innovation leaders rather than as followers (as was the case in the previous mode) to reap first-mover advantage. The choice of biotechnology investments was undertaken in this context. It was also important for Singapore to counter the strong competition coming from other regional players who were moving fast to bridge the gap with Singapore in high-technology industries such as semiconductors and electronics. The rising labor costs resulted in rapid relocation of low value-added manufacturing jobs from Singapore to neighboring countries. The rise of China as the "factory of the world" also posed a serious threat to Singapore's reliance on manufacturing industries for sustaining economic growth. Therefore, Singapore's continued growth and development is dependent on becoming a knowledge-based economy that can be integrated with the global market such that its economy will not become captive to sudden regional challenges in the future. In order to advise the Singapore Government to "remake" Singapore to address these challenges, an Economic Review Committee (ERC) was set up by the Singapore Government in December 2001. The ERC Report submitted in February 2003 outlines three key recommendations to remake Singapore into:³⁵

a globalized economy, such that it will be a node in the global economic network linked to all major economies of Asia (Japan, China, India) and beyond (EU, North America);

an entrepreneurial and creative nation that is willing to take risks to create new businesses and industries; and
a diversified economy powered by the twin engines of manufacturing and services.

The Singapore Government's strategy is to creatively map out the secrets behind such globally acclaimed cluster-driven innovation leaders as Silicon Valley, Bio Valley (Delaware-Philadelphia area), Research Triangle Park, and San Diego in the United States along with Israel, Ireland, and Taiwan. The way to go about creating such an environment for a high-tech innovation-spurred economy is to recreate the economy through molding entrepreneurial universities, incubator facilities, industry-university spin-off firms, and joint institutional efforts between universities, industries, and government.³⁶ It would involve plunging headlong into the unmarked frontiers of a knowledge-based economy.

Governmental Research System

The innovation system in Singapore appears to have made some headway towards the triple helix framework. The central concern of the government is to create an innovation milieu of trilateral initiatives for knowledge-based economic growth through facilitating strategic alliances among firms, national research centers, statutory boards, academic research groups, and university spin-off firms. These arrangements are encouraged and initiated by the government through the implementation of "new rules of the game" (such as revamping intellectual property rights regime); through direct or indirect financial assistance for R&D; and, most importantly, through creatively restructuring the governmental statutory bodies that had done an excellent job in the previous NIS mode. Such trends are a clear indication of the local innovation system evolving. The restructuring of the EDB and the National Science and Technology Board (renamed as A*STAR—Agency for Science, Technology and Research in 2002) seeks to accommodate the flexibility and changeability needed at the governmental level to conform to the new entrepreneurial innovation milieu. The EDB is reinventing itself to make Singapore a "compelling global hub for business and investment." A*STAR proclaims its mission as fostering "world class scientific research and develop talent for a vibrant Knowledge-Based Singapore."³⁷ Through its commercial arm "Exploit Technologies," A*STAR claims to make the scientific research undertaken by its research institutes profitable.³⁸

The government has embarked on a coordinated effort to encourage innovation and entrepreneurship through improving the linkages between local universities and industries. Public research institutes and centers were mandated to work closely with firms and to recover part of their R&D expenditures from these industrial sources. A*STAR monitors the performance of research institutes in patenting, licensing of technologies, and joint R&D ventures with private firms. The government has initiated an ambitious mission to expand the existing Science Parks to specialist parks (catering to specific industries such as pharmaceuticals, bio-medicals, new media, and IT) to encourage

better university-industry interaction. A state-of-the-art “Biopolis” (a biomedical-research-park-cum-residential-and-recreational-complex) was opened in October 2003 in the Buena Vista Science Hub adjacent to the National University of Singapore/National University Hospital campus with much fanfare. Spread over eight hectares with seven architecturally unique buildings, the Biopolis is intended to be a research campus within an urban park for biomedical researchers to “work, live, play, and learn.”³⁹ The Singapore Government’s ambition is to make this one of the most conducive and integrated innovation centers in the world for developing the biomedical industry cluster.

Entrepreneurial Universities

The most plausible evidence of the emergence of a triple helix mode of innovation can be gleaned from the recent expansion of the portfolios of the two local universities—National University of Singapore (NUS) and Nanyang Technological University (NTU). These state universities are being given greater autonomy to be competitive in the fast-emerging educational services sector of Singapore.⁴⁰ They are now adding—to their traditional roles of training scientific, engineering, and managerial manpower—such new roles as forming and incubating university spin-off firms and stimulating innovation and entrepreneurship among the university community. Universities are being asked to contribute to the economy in real time. The Industry and Technology Relations Office (INTRO) at the National University of Singapore (NUS) reports the formation of scores of spin-off firms since its inception in 1992, while the Innovation and Technology Transfer Office (ITTO) at Nanyang Technological University (NTU) is currently incubating numerous high-tech start-ups. In addition to collaborating with the twelve Research Institutes under the A*STAR, there are several university-level research centers at NUS and NTU.

A clear transformation of the university’s role can be observed in Singapore because of the proliferation of academic linkages between local and foreign educational institutions. Both local universities are forging academic and research linkages with foreign counterparts in the Asia-Pacific, Europe, and North America. In 1997, the EDB launched funding for a World Class University (WCU) scheme to attract top foreign universities to set up significant presence in the academic sector in Singapore. The selected universities are to represent the best in their fields across a wide spectrum of disciplines, such as engineering, applied sciences, and management. These institutions are expected to conduct postgraduate courses, undertake research, and build-up strong linkages with industry and local academics. In the area of graduate business education, the University of Chicago Business School, INSEAD, and Macquarie University (JV with Singapore Technologies) have opened campuses in Singapore. The EDB is in discussion with prestigious foreign universities to open campuses in Singapore to offer comprehensive undergraduate and graduate education in competition with the local state universities.⁴¹ The government has decided to grant more autonomy to the local state universities so that they can be “nimble-footed to

respond to market changes and can hold their own against overseas universities."⁴²

The Singapore-MIT Alliance (SMA), for instance, is a new program initiated by NUS to impart engineering education and research collaboration among faculty and students within the engineering faculties at MIT, NUS, and NTU. SMA students participate in industrial projects through structured internships with specific firms and enterprises as well as enroll in graduate degree programs. MIT has recently decided to confer graduate degrees to SMA students, who will also receive degrees from NUS or NTU. SMA students are expected to come up with creative solutions to complex issues and apply them to resolving actual industry-related problems. In general, SMA students are given the challenging opportunity to work with industry partners, famous academics, and the Research Institutes to solve complex real-world problems on the innovation front.⁴³

The motto of NUS is: "Towards a global knowledge enterprise." One sign of NUS's attempt to re-brand and re-make itself as an entrepreneurial university was the setting up of the "NUS Enterprise" by bringing together and consolidating several industry outreach, research support, and liaison offices within the university. The proclaimed vision of the NUS Enterprise is "Creating value from knowledge," and its mission is "To promote and foster an enterprise culture in the campus community by serving as a catalyst of innovation and entrepreneurship, and to nurture talents with a global mindset."⁴⁴ Establishing NUS Overseas Colleges in foreign locations where innovation and entrepreneurship thrive is a high priority of NUS Enterprise. The NUS College in Silicon Valley was established with this objective in July 2001. The main mission of this largely virtual college, according to NUS Enterprise, is to "cultivate dynamic and resourceful entrepreneurs by immersing a selected group of NUS students in the entrepreneurial and academic environment in Silicon Valley. Students will return with a paradigm shift in mindset, motivated to promote the entrepreneurial spirit among NUS students and create an entrepreneurial hub in Singapore."⁴⁵ NUS students participating in the program spend a year as interns in selected technology-based start-ups. They also attend entrepreneurship and discipline-based courses at Stanford University. The second NUS Overseas College, NUS College in Bio Valley (NCBV), was set up in July 2002 in Philadelphia. According to NUS Enterprise, at NCBV, selected NUS "students will intern with biomedical and biotech startups at Bio Valley which is located within central Philadelphia and surrounded by the comprehensive scientific and industrial development of the Delaware Valley."⁴⁶ Through NCBV, NUS students could take courses at the University of Pennsylvania and get trained at UPenn's Technology and Entrepreneurship Immersion Program (TEIP). The newest NUS overseas college is NUS College in Shanghai (NCS), established in July 2003. Designed to build on the experiences of NCSV and NCBV, NCS is intended to allow NUS students spend a year in Shanghai as interns in technology companies and attend entrepreneurship courses at Fudan University in Shanghai.⁴⁷

These overseas ventures are expected to form a node in the interactive communication network of university-industry relations. The emerging role of Singapore academe in this network is also evidenced by the collaborative arrangement between NUS and local high-tech firms such as Singapore Technologies Group (STG) to “promote entrepreneurial culture and technology spin-offs.”⁴⁸ All these developments show that Singapore universities are attempting to become the “entrepreneurial universities.”⁴⁹

Industrial Networks

The largest contributor of R&D expenditure in Singapore is the industrial sector. As expected by the EDB, the private sector in the past few years has outspent the public sector in R&D expenditure by nearly four times.⁵⁰ There is also a clear trend in the rate of patent application by private firms in Singapore. Joint R&D activities between foreign MNCs and local public research institutions have flourished in recent years.⁵¹ Many foreign companies have indicated their intention of continuing to undertake R&D activities in Singapore despite many of them moving their manufacturing base to lower-wage countries in the region.⁵²

Governmental assistance for innovation was initially concentrated on fostering electronics, precision engineering, and information technology (IT) industries. However, because of the dot-com bust of 2000 and the inability to create IT industries due to the lack of qualified manpower forced the government to look at biotech applications in life sciences as the new innovation frontier to conquer.

The Dynamics of Innovation in the Biomedical Sciences Cluster: 2000-Present

Biotechnology, pharmaceuticals, medical devices, health care services, and bioinformatics are the five sub-clusters identified under the biomedical sciences cluster by the policy-makers within the EDB.⁵³ The Singapore Government’s declared intention is to become a world-class R&D center in selected sub-clusters in this strategic research-intensive industry. It intends to create R&D facilities for the study of diseases common to Asia; to become a regional center to develop new drugs, genetic medicine, and gene therapy; and to provide an array of services for the needs of the global biomedical sciences industry.

Singapore’s plunge into the biomedical industry is a natural step given its determination to become a knowledge-based economy. The Singapore Government’s declared plan is to erect a “fourth pillar” to support and sustain the manufacturing sector by nurturing biomedical sciences.⁵⁴ Being a land-scarce country, agricultural biotechnology—a well-trodden area in Europe and North America—was not an area that Singapore could hope to exploit.⁵⁵

Biomedical sciences may well suit to Singapore’s existing position as a nation with good medical institutions and universities. Because of the potential of growth and development, it appears that biomedical sciences became a natural entry point for nurturing a new industrial cluster where no other country

in the region has achieved absolute monopoly or first-mover advantage. What IT and semiconductors did for Silicon Valley, biomedical sciences are expected to deliver for Singapore. However, it is a high risk/reward venture compared to what Singapore and its firms have experienced hitherto.

Biomedical Knowledge Network and the Birth of Biopolis

In June 2000, the Singapore Government formed a high-level Ministerial Committee chaired by Deputy Prime Minister Dr. Tony Tan to oversee the development of biomedical sciences in Singapore. The Ministerial Committee included the Minister of Education, the Minister of Trade and Industry, and the Minister of Health. The mandate of the committee was to oversee the various aspects of education, R&D, and industry development. The Ministerial Committee was supported at a working level by the EDB, A*STAR, JTC, NUS, NTU, and senior bureaucrats from a few other ministries and statutory boards and agencies. An International Advisory Council (IAC) chaired by Richard Sykes, Rector of Imperial College and former Chairman of the Board of GlaxoSmithKline Plc., was also established to advise the Ministerial Committee and the working groups. The members of the IAC are distinguished scientists and heads of major well-known Western research institutes. Their expertise spans a wide spectrum of biological fields such as molecular and cell biology, biomedicine, biochemistry, and biophysics. The IAC include Nobel laureates David Baltimore, Stanley Cohen, and Sydney Brenner (co-chair of IAC), among other luminaries of modern biological sciences.⁵⁶

At the level of actually formulating and implementing programs and imparting funds, EDB acts as the nodal agency. EDB has set up a Biomedical Sciences Group (BMSG) to organize a range of biomedical sciences funding activities and provides infrastructural support to these activities. Investment in biomedical industries is directed through the Biomedical Sciences Investment Fund (BMSIF). Funding and start-up capital are provided through its Biomedical Sciences Innovate 'N Create Scheme (BMS INC). It also provides tax incentives and venture capital for the set up of startup firms and institutions.⁵⁷

A*STAR acts as the main R&D bridge and interlocutor between the government, industry, and university. A Biomedical Research Council (BMRC) formed in October 2000 within A*STAR supervises and supports biomedical R&D work in Singapore. A*STAR provides local and global linkages for Singapore-based firms and research institutes through its signed MOUs with the objective of developing research cooperation and collaboration with world-class universities and research organizations.⁵⁸ EDB/BMS Group and BMRC/A*STAR work together to create the intellectual, industrial, and human capital in the biomedical sector to nurture and sustain industrial enterprises. Enhancing core capabilities in biomedical sciences is entrusted to the five A*STAR research institutes under BMRC—Institute of Molecular and Cell Biology (IMCB),⁵⁹ Bioprocessing Technology Institute (BTI), Bioinformatics Institute (BII), Genome Institute of Singapore (GIS), and the recently founded Institute of Bioengineering and

TABLE I. Biomedical Research Capacity in the Public Research Institutes of Singapore

Institute	Established	Staff*	Number of Publications*	Patents Filed*	Core Competency
IMCB	1987	380	987	206	Cell cycling, signaling, death, motility; protein trafficking; apoptosis; developmental biology; genomics; infectious diseases
BTI	1990	126	67	3	Bioprocess R&D for bio-pharmaceutical industry; cell line engineering; animal cell technology; microbial fermentation; downstream processing; product quality & stabilization; proteomics
GIS	2000	112	4	3	Integration of genomic technology & biology; stem cell biology; biological investigations for individualized medicine; proteomics
BI	2001	40	0	0	Distributed computing in biomedicine; systems biology; structural & functional genomics; computational genomics; medical informatics; theoretical biology; mathematical biology
IBN	2002	53	2	9	Tissue & stem cell engineering; biomaterials & scaffold; medical devices & delivery systems; nano-technology; combining nano-electronics & biology

* as of December 2002.

Source: A*STAR Singapore and Yeo [note 89].

Nanotechnology (IBN). Table 1 provides statistical details and descriptions of the core competencies of these five key research institutes.

The EDB was able to lure Edison Liu, who was director of clinical science at the National Cancer Institute in the United States, to head the Genome Institute of Singapore.⁶⁰ Attracted by the resources and fewer restrictions on controversial research fields such as stem cell biology, several highly qualified biomedical scientists have moved to Singapore in recent years. One such recent arrival is stem cell researcher Phillippe Taupin from the renowned Salk Institute for Biological Studies in California.⁶¹ Another famous foreign talent to arrive in Singapore recently is the noted British cancer researcher, David Lane, who has taken over the helms of IMCB as its executive director.⁶² In addition to bringing talent from overseas, the human capital needed for the biomedical sciences industry is to be attained by enhancing the core biological and biochemical educational capabilities of NUS and NTU. For example, NTU recently opened

a School of Biological Sciences with state-of-the-art facilities for research and training. Since 2001, NSTB (A*STAR since 20002) has launched the National Science Scholarships (NSS) scheme to provide scholarships to Singaporeans to pursue higher studies, research and training abroad in biomedical science disciplines.⁶³ The popularity of biomedical sciences as an attractive career option for Singapore students is highlighted by the high demand for a new industry-specific undergraduate program in life sciences at the newly opened School of Biological Sciences at NTU.⁶⁴

The JTC Corporation is building a state-of-the-art biomedical park (the appropriately christened Biopolis) in the heart of Singapore Science Park hub next to the National University. Phase I, costing S\$500 million, of this biomedical research park was opened in October 2003. The facilities of the Biopolis include research institutes, incubator centers for start-ups, medical facilities, and space for private firms. Unlike the existing Science Parks I and II with low-lying buildings and lush tropical feeling surrounded by trees and manicured lawns, Biopolis is designed to have a city feel with tall buildings and condominium living and facilities for entertainment and nightlife.⁶⁵ Manufacturing activities related to pharmaceutical and biotech products are located at the Tuas Biomedical Park, formerly known as Tuas View Pharma Park.

The biomedical sciences industry cluster showed marked increase in manufacturing output in 2002 despite the global recession. Biomedical industry cluster manufacturing output in 2002 was S\$9,700 million, a 47 percent increase from the output level of 2001. The value-added from this cluster stood at 18 percent of total manufacturing value-added, although it accounted for only 7 percent of total manufacturing output in 2002. The manufacturing output was S\$11,300 million in 2003 and it is expected to be over S\$12,000 million in 2004. Table 2 shows the biomedical industry performance statistics for the past seven years.

Leading biomedical industry players in the pharmaceutical sector include AstraZeneca, Aventis, Eli Lilly, GlaxoSmithKline, Kaneka, Merck & Co., Novartis, Novo Nordisk, Pfizer, Pharmacia, Sanofi-Synthelabo, Schering-Plough and Wyeth; biotech sector include Agenica, ES Cell International, KOOPrime, Prologo, MerLion Pharmaceuticals, PharmaLogicals Research, pSiOncology, Qugen, S*BIO and Viacell; and the medical technology sector include Applied Biosystems, Baxter, BD (Becton Dickinson), Boston Scientific, JMS (Japan Medical Supply), Johnson & Johnson Medical, Siemens Medical Instruments and Tyco Healthcare.⁶⁶ Two large pharmaceutical MNCs established R&D centers in Singapore—Eli Lilly set up a Systems Biology lab and Novartis set up an Institute for Tropical Diseases—and commenced operation in 2002.⁶⁷

Singapore's strategy is to nurture and develop SMEs in the biotech industrial cluster, a strategy distinct from the earlier approach of building-up large state-linked firms in the electronics industry.⁶⁸ The biomedical sciences cluster saw a significant increase in the formation of several local startups in pharmaceutical, medical technology, health care services, and biotechnology sub-clusters. Startups such as ES Cell International, S*Bio, Genset and Oculex are

TABLE 2. Biomedical Sciences Industry Statistics

Year	Manufacturing Output (\$ million)	Percentage Increase	Value-Added (\$ million)	Percentage Increase
1997	2,600	—	1,900	—
1998	4,000	53.8	2,700	42.1
1999	6,300	57.5	2,500	-7.4
2000	6,400	1.6	3,800	52.0
2001	6,800	6.3	3,700	-2.6
2002	9,700	42.6	5,800	56.8
2003	11,300	16.5	6,900	18.9
2004	12,180 (projected)	7.8	N.A.	—

Source: EDB Annual Report 2002/03, Singapore, <<http://sedb.com/edbcorp/sg>>. 2003 numbers are nominal and 2004 numbers are projected. A*STAR and EDB Joint Media Release, February 19, 2004 at <www.nstb.gov.sg/astar/about/action/about_pressrelease_details.do?id=0f9ff8fb01fQ>; *The Economist*, August 14, 2004.

engaged in a wide range of activities such as basic R&D, product and process development, clinical trials, and production of diagnostic devices.

A startup founded in 2000, ES Cell International (Singapore) conducts research on human embryonic cells and develops and commercializes stem cell technologies. Its core business focus is understanding human embryonic stem cell regulation, differentiating cell populations, and stem cell therapies. This pioneering start-up is based at the National University Hospital and has collaborative arrangements with Hadassah University in Israel and Monash University in Australia. ES Cell could make Singapore the leader in stem cell research in the world and also a significant supplier of stem cells.⁶⁹ ES Cell International recently made news by luring British cloning expert, Dr. Alan Colman, to become its chief scientific officer.⁷⁰ Dr. Colman’s research focus is expected to be on finding stem cell-based cure for diabetes. His research program is to transform embryonic stem cells into cells that could secrete insulin so that diabetics need not have to rely on insulin injections.⁷¹ If successful, such an innovation could become a windfall for ES Cell as well as Singapore for the simple fact that Asia has the largest number of diabetics in the world.

Also founded in 2000, S*Bio was Singapore’s first fully integrated genomic and small molecule-based drug discovery company. This venture was formed through an alliance between PharmBio Growth Fund Pte Ltd. (a dedicated life sciences fund managed by the EDB), Chiron Corporation, and Blue Dot Capital Pte Ltd. (a subsidiary of Singapore Technologies). The mission of S*Bio is to discover and develop new drugs, vaccines, and therapeutic and diagnostic products.⁷²

The emerging innovation system in the biomedical industrial cluster shows the evolution of a rudimentary triple helix of state-university-industry interaction, albeit one that is strongly state-directed. The five biotechnology-

related Research Institutes under the A*STAR overlap the three key players. The boundaries of the three institutional players are not rigid as before and the reflexive nature of the interaction is likely to transform the structure and agency of the innovation partners. Despite the fact that the state acts as the nodal agency, the relationship between the state and the other two agents is complex and non-deterministic. The proof for the formation of a dynamic triple helix framework would be visible only when we can see signs of self-organization and synergy. Despite the rather promising prognostication on the health of these new biotech ventures, it is difficult to predict the longer-term viability of biotech investments. This is because of the lack of a clear industrial strategy evident in the declared objectives of the EDB based on its published pronouncements. Ultimately, the real test of the emergence of such model of innovation would be the market test, to be expected in the next several years.

Assessment of Innovation & Competition Strategy in the Biotech Sector

While electronics was the pre-eminent leading-edge technology of the twentieth century, biotechnology appears to be the dominant technology of the twenty-first century. However, being a nascent field, the innovation trajectories and new product and process development in the biotech domain are still unclear and uncertain. Based on existing trends, the uncertainty associated with biotech innovations is comparatively high vis-à-vis such established clusters as electronics and chemicals. Most importantly, biomedical investments assume high risk because of the lack of clear market demand signals. While the benefits could be immense (because of increasing returns, the lock-in nature of biomedical products, and first-mover advantages for established firms),⁷³ there is also the potential risk of putting all the investment eggs in one basket. Singapore's ongoing biomedical industrial strategy is to create clusters in pharmaceuticals, biotechnology, medical technology, and health care services. The biomedicine sector is expected to generate US\$7 billion in revenue in 2004.⁷⁴ Much of this increase in output is attributed to multinational pharmaceutical companies that have established production plants in Singapore. For example, U.S. pharmaceutical multinational Schering-Plough alone has invested nearly a billion U.S. dollars in Singapore for several bulk manufacturing facilities.⁷⁵ Another U.S. pharmaceutical multinational, Pfizer, recently opened a S\$600 million plant in the Tuas Biomedical Park to manufacture active pharmaceutical ingredients (APIs).⁷⁶ Singapore's stated objective for its huge investments in biomedical industrial sector is to turn it into a "Biopolis of Asia." The goal is to reap benefits through huge investments in pharmaceutical and medical devices manufacturing, drug discovery, R&D services, clinical development, and headquarters activities. The Singapore Government's objective is to generate US\$12 billion from this sector by 2010.⁷⁷

The longer-term objective of entering the huge and lucrative American and European markets may not be a smooth ride due to the prohibitively

expensive drug regulatory regime in these countries. Fledgling Singapore biomedical firms may not be in a position to confront, head on, the regulatory hurdles of the U.S. FDA. Because of the rather long drug discovery to patenting time of over ten years, it would be beyond the capacity of most startups and SMEs in the industry to survive such long and expensive regulatory scrutiny of their new inventions. Of course, they may get government support for R&D or venture capital funds for meeting some operating expenses, but these outside interventions in themselves may not be sufficient. For a thriving biomedical industrial cluster to emerge, Singapore must have the determinants of national competitive advantage to mold this industrial cluster.

Singapore's best niche strategy may be to channel biotech investments first for developing biomaterials that could bypass a frontal regulatory confrontation with the FDA. The regulatory process may be much shorter and less expensive for biomaterials than drugs. In order to chart the strategy for this new venture, EDB may want to revisit the path Singapore adopted in the mid-1960s to develop its marine industry. Without following the leaders Japan and Korea into shipbuilding, Singapore made a strong presence in ship repair without actually building massive shipyards. Investments in four major docks and several smaller ones paid off handsomely, as did huge complementary investments in ports, container terminals, and chemical complexes. Singapore eventually became the world's largest ship repair hub. By 1981, Singapore's marine industry (including ship repair, shipbuilding and other marine services) had a total revenue of S\$2.4 billion.⁷⁸

The corresponding niche strategy for biomedical investments may be to first build extensive R&D, product development, testing, and manufacturing facilities for various biomaterials, with an objective to derive indirect benefits by leveraging the expertise gained from biomaterials for ventures in drug discovery, bio-pharmaceuticals, and genetic medicine. The demand conditions for biomaterials are much clearer than for genetic medicine. Even a twin-track strategy of even-handedness in investing in both sectors could work in Singapore's favor.

There are more practical challenges the government must address to revamp and reconfigure the innovation environment for the biomedical industry in Singapore. While both the NIS and triple helix models do not provide concrete evaluative guidelines to study and measure competitiveness, relevant aspects of Porter's and Furman et al.'s⁷⁹ determinants can be used to evaluate Singapore's competitive advantage and innovative capacity.⁸⁰

The most important determinant of national competitiveness is the presence of a strong knowledge base in biomedical sciences, which, in turn, requires a huge supply of highly skilled research scientists and technicians. The knowledge base can be constructed only if a large amount of money is earmarked for R&D activities and building world-class research centers and universities. Compared to other industrialized nations, Singapore's R&D expenditure has been relatively low until a few years ago. In 2000, the Gross Expenditure on R&D (GERD) was only 1.88 percent of the GDP. The GERD had improved to 2.11

percent in 2001, although this target was set for 1995.⁸¹ According to government statistics, total R&D expenditure for 2002 was S\$3,405 million, which was 2.19 percent of GDP.⁸² These latest numbers are impressive, but still low compared to many industrialized nations. This situation is changing, as the government is promising to spend huge amount of R&D money for biomedical sciences.

Singapore might have the resources to construct the R&D infrastructure, but what about the human capital needed to build up the knowledge capacity? There is a tremendous shortage of qualified Singaporeans in the biomedical sciences. Can Singapore depend on foreign talent to follow the money trail? Singapore's biomedical industry analyst Ai-Lien Chang puts Singapore's challenge in retaining the foreign talent rather vividly, "The challenge is to resist the temptation to pull back, especially with grants, when breakthroughs are slow in coming, or when the country's economic fortunes are hit hard."⁸³ Human capital is the most important element for all research-intensive industries, including biomedical sciences. Therefore, how to train, consolidate, and retain the immense human capital required for the creation of a viable biomedical sciences industry is going to be a tremendous challenge.

Another important factor is intellectual property protection and its adjudication. Since numerous foreign MNCs, universities, research institutes, and individuals own patents on gene segments, sequencing, and decoding processes, obtaining the knowledge that is owned by others will be a daunting legal and financial problem. Singapore is addressing these complex intellectual property issues through the setting up of an Intellectual Property Academy.

Another important determinant of competitiveness is demand conditions. Creating a dynamic innovation environment requires an examination of the role the public plays in the demand for and the diffusion of innovation—a problem that the NIS, triple helix, and Porter's diamond fail to address adequately and one that has special salience to Singapore. Furman et al. have shown the importance of public support for basic research and legal protection of intellectual property for creating "innovative capacity."⁸⁴ In the concept of the three stakeholders of innovation—government, industry, and academe—there is a key stakeholder left out—namely, civil society, made up of consumers and non-governmental organizations (NGOs).⁸⁵ As in the case of agricultural biotechnology, specifically with regard to genetically modified food, the innovation trajectory is highly influenced by consumers, farmers, and NGOs.⁸⁶

Biomedical sciences will not be any different from agricultural biotechnology where civil society played a key role in molding its technological trajectory and demand conditions, especially in Europe.⁸⁷ In fact, the moral and ethical questions will be even more daunting in the biomedical field, and its innovation trajectory will be affected by how both the local and transnational civil societies mediate and resolve these issues. The weakness of civil society in Singapore could be a critical factor given the ease with which stem cell research was able to flourish in Singapore in the absence of public scrutiny of this contested research area. This probably explains why Singapore became one of the world's foremost

stem cell research centers. A recently arrived noted stem cell researcher from the United States, Phillippe Taupin, attests to this fact. Taupin came to Singapore because “there are fewer ethical and political minefields than in the West, and Singapore has pledged a strong commitment to stem cell biology.”⁸⁸ This may be true, but since the lion’s share of demand for the products and cures coming out of stem cell research must be found outside of Singapore because of the small domestic market, any lingering ethical concerns will then be left to the international market place and concerned civil society organizations to scrutinize. Anticipating the ethical and moral issues stemming from biomedical research, the Singapore Government did set up a Bio-ethics Advisory Committee (BAC) in December 2000. Nonetheless, the BAC is made up entirely of legal, governmental, scientific, and health care professionals. Representatives from civil society and religious organizations are not found on the BAC, and furthermore it was restricted to dialogue sessions and discussion forums.⁸⁹

Since civil society is severely curtailed by the state in Singapore, and there seems to be no movement on the part of the government to facilitate an unhindered civil society, the social and cultural acceptability test of biomedical products may not take place in Singapore. Also, due to the limited extent of the local market, any social acceptability tests of biomedical products and services conducted locally may also be insufficient to satisfy the international consumers. Initiating public consultations, nevertheless, would augur well for Singapore’s credibility as an open society with good ethical standards, which, in turn, could sway public perception and opinion in the international community. Since it expects to play in the global technology markets in Europe and North America, the Government must pay attention to these demand conditions outside of Singapore.

A clear lesson from Singapore that has relevance to other states is that to become global players, states should not only give more space and influence to markets, firms, and universities, but they should also involve the larger public to expand the “innovative capacity” of nations. States must also realize that civil society will flourish only under full democratization of all facets of society. Informal networks and alliances are key ingredients of innovation and the creative economy. The success of such innovation habitats as Silicon Valley⁹⁰ have been based on bottom-up initiatives and interaction, whereby power was distributed and reciprocity nurtured by voluntary adherence to norms. Networks and alliances were built upon mutual trust and cooperation in an environment that allowed information and resource sharing. Whereas previously the state built strong ties with the corporate sector, it must now extend those ties to a broader range of stakeholder groups to forge industrial policies in high-technology industries.⁹¹ Rather than assuming, as many former and present developmental states continue to do, that winners can be picked—as they had done in the earlier phase of their industrialization—they must now spread their investment decisions more widely to enable more possibilities to emerge.

Conclusion

Singapore's remarkable industrial development and economic growth since independence was attributed to its single-minded effort to transfer, adopt, and adapt foreign technologies based on policies formulated and implemented by a paternalistic developmental state. While other developing countries were following import substitution industrialization during the 1960s and 1970s, Singapore (like its "tiger" cohorts South Korea, Taiwan, and Hong Kong) took the track of export promotion industrialization as its key to prosperity by inviting foreign MNCs who had the technology and knowledge that the fledgling state needed. As Singapore's first Prime Minister Lee Kuan Yew candidly admits, "The story of Singapore's progress is a reflection of the advances of the industrialized societies—their inventions, technology, enterprise, and drive."⁹² The innovation system that emerged, early on, was clearly systemic in orientation. Industrial transformation policy was guided and regulated by the state as part of a concerted nation-building project. The NIS that emerged in Singapore had a clear objective of promoting technological capability through enhancing process innovation during the early stages to product innovation. As Mathews and Cho have shown, technology and resource leveraging was the core principle of state industrial policy to create the manufacturing industrial sector.⁹³ Local firms developed learning capability and the links between the actors of innovation were hierarchical. Government took up the responsibility to facilitate funds for R&D, education, and infrastructural development.

Recently, the mode of innovation, especially in the biomedical industry in Singapore, has shown signs of transition from a vertically oriented system to a horizontal mode involving the state, industry, and academe. A key facet of this transition was the role attributed to the university sector to foster innovation, enterprise, and entrepreneurship. While the state still dominates the evolving innovation matrix in the biotech sector of Singapore, the academic sector will find it much easier to encourage enterprise and entrepreneurship as it gains more autonomy from the state. In the case of Singapore, however, the state still exerts too much control over innovation policy. It will be interesting to see if the government can really play the role expected of it within the context of the triple helix system, although the government claims it is committed to implementing reforms by loosening its control over almost all aspects of social, political, and economic space in the republic. Interestingly, some positive developments are taking place on the cultural front.⁹⁴ How to get people think for themselves when the state used to do the thinking for them is a crucial issue to be dealt with. It is possible to construct a knowledge society, a "learning" and "thinking" nation, when conformity is the norm for social action?

Biotech investments at the moment appear to bear high risks due to the speculative nature of the emerging innovations and the rather amorphous and unclear market signals coming out of the biotech industry. On the other hand, as technologies become more speculative, governments should spread their investment bets more widely to maintain economic fortunes in a volatile economic environment. The more general lesson that states could learn from Singapore

is that there is no “right” innovation policy that government planners can follow, rather they must be nimble enough to cope with uncertainties related to industrial planning in a world driven by innovation and change.

Notes

1. See J.A. Mathews, “A Silicon Island of the East: Creating a Semiconductor Industry in Singapore,” *California Management Review*, 41/2 (Winter 1999): 55-78.
2. For more on uncertainty and innovation, see N. Rosenberg, “Uncertainty and technological change,” D. Kneef, G.A. Siesfeld and J. Cefola, eds., *The Economic Impact of Knowledge* (Boston, MA: Butterworth-Heinemann, 1998), pp. 17-34.
3. For more on the theory of clustering of innovations and the dynamics of technology development, see G. Parayil, “Mapping Technological Trajectories of the Green Revolution and Gene Revolution from Modernization to Globalization,” *Research Policy*, 32/6 (2003): 971-990.
4. M.E. Porter, “The Competitive Advantage of Nations,” *Harvard Business Review*, 68/2 (March/April 1990): 73-93, quote on p. 73.
5. Incidentally, based on his research during the late 1980s, Michael Porter claimed that Singapore’s policy of leveraging foreign multinational corporations for its industrialization was a poor economic development strategy. According to Porter, “Foreign multinationals should be only one component of a developing nation’s economic strategy, and an evolving component. At some stage in the development process, the focus should shift to indigenous companies. In Singapore....my view is that the shift has been too little and too late.” M.E. Porter, *The Competitive Advantage of Nations* (New York, NY: Free Press, 1990), p. 679. However, Mathews as well as Mathews and Cho have shown that Porter was not entirely right about this argument, a position further supported in this article. Mathews, op. cit.; J.A. Mathews and D.S. Cho, *Tiger Technology: The Creation of Semiconductor Industry in East Asia* (Cambridge: Cambridge University Press, 2000)
6. The exponents of the triple helix framework, Etzkowitz and Leydesdorff concede this. H. Etzkowitz and L. Leydesdorff, “The Dynamics of Innovation: From National Systems and “Mode 2” to a Triple Helix of University-Industry-Government Relations,” *Research Policy*, 29 (2000): 109-123.
7. Although an aside, this article follows the neo-Schumpeterian evolutionary theory. For the basis for explaining economic growth of Singapore and other Asian newly industrialized countries (ANICs), see R.R. Nelson, H. Pack, and The World Bank, “The Asian Miracle and Modern Growth Theory,” Policy Research Working Paper No. 1881, Development Research Group, The World Bank <<http://econ.worldbank.org/docs/509.pdf>>; H. Pack, “Research and Development in the Industrial Development Process,” in L. Kim and R.R. Nelson, eds., *Technology, Learning, and Innovation: Experiences of Newly Industrializing Economies* (Cambridge: Cambridge University Press, 2000), pp. 69-94; M. Hobday, *Innovation in East Asia: The Challenge to Japan* (London: Edward Elgar, 1995); C. Dhalman, “Technology Strategy in East Asian Developing Economies,” *Journal of Asian Economics*, 5 (1994): 541-572. In contrast, for the neoclassical theory of factor (capital) accumulation as the basis for economic growth and not allegedly due to productivity increase of factors of production, see A. Young, “The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience,” *Quarterly Journal of Economics*, 110/3 (1995): 641-680; L.J. Lau, “The Sources of East Asian Growth,” in F.G. Adams and S. Ichimura, eds., *East Asian Development: Will the East Asian Growth Miracle Survive?* (West Port, CT: Praeger, 1998): 41-67. Using the growth accounting methodology pioneered by Robert Solow, the neoclassical “accumulationists” claim that Singapore and other ANICs show very low or even negative (in the case of Singapore according to Young) total factor productivity (TFP). The “assimilation” approach of evolutionary theorists argue that Singapore and other ANICs grew due to productivity growth attributed to technological learning, capability acquisition, and innovation. For an interesting sketch of the “assimilation” versus “accumulation” argument, see I.P. Mahmood and J. Singh “Technological Dynamism in Asia,” *Research Policy*, 32/6 (2003): 1031-54. For a thorough critical appraisal of neoclassical economists’ theoretical and empirical approach to ascertaining TFP and a rebuttal of their claim of Singapore’s zero or negative TFP, see

- J. Felipe, "On the Myth and Mystery of Singapore's 'Zero TFP'," *Asian Economic Journal*, 14/2 (2000): 187-209.
8. On innovation trajectories and technology development, see Parayil, op. cit.
 9. J.L. Furman, M.E. Porter, and S. Stern, "The Determinants of National Innovative Capacity," *Research Policy*, 31 (2002): 899-933.
 10. K.Y. Lee, *From Third World to First: The Singapore Story, 1965-2000* (New York, NY: HarperCollins Publishers, 2000).
 11. The average real GDP growth for the period 1965-2000 was computed from K.W. Li, *Capitalist Development and Economism in East Asia: The Rise of Hong Kong, Singapore, Taiwan, and South Korea* (London: Routledge, 2002), p. 26.
 12. Economic Review Committee (ERC), *Report of the Economic Review Committee: New Challenges, Fresh Goals—Towards a Dynamic Global City* (Singapore: Ministry of Trade and Industry, 2003).
 13. P.K. Wong, "Leveraging Multinational Corporations, Fostering Technopreneurship: The Changing Role of S&T Policy in Singapore," *International Journal of Technology Management*, 22/5-6 (2001): 539-567, 541.
 14. P.K. Wong, "The Role of the State in Singapore's Industrial Development," in P.K. Wong and C.Y. Ng, eds., *Industrial Policy, Innovation and Economic Growth: The Experience of Japan and the Asian NIEs* (Singapore: Singapore University Press, 2000), pp. 503-579.
 15. The rapid expansion and upgrading of these crucial service sectors would not have been possible without the technological deepening of the country attained through technological capability building in high-tech manufacturing industries.
 16. W.G. Huff, "The Developmental State, Government, and Singapore's Economic Development Since 1960," *World Development*, 23/8 (1995): 1421-1438.
 17. "Face Value: Singapore's Man with a Plan," *The Economist*, August 14, 2004, p. 54.
 18. See Mathews and Cho, op. cit.; P.K. Wong and C.Y. Ng, "Singapore's Industrial Policy to the Year 2000," in S. Masuyama, D. Vandenbrink, and C.S. Yue, eds., *Industrial Policies in East Asia* (Tokyo: Nomura Research Institute/Singapore: Institute of Southeast Asian Studies, 1997), pp. 121-141.
 19. D. McKendrick, R. Doner, and S. Haggard, *From Silicon Valley to Singapore: Location and Competitive Advantage in the Hard Disk Drive Industry* (Stanford, CA: Stanford University Press, 2000).
 20. See Mathews and Cho, op. cit.
 21. The institutional mechanisms of technological learning include licensing, foreign direct investment (FDI), joint ventures, subcontracting, overseas training and education, hiring, foreign acquisition, and joint ventures. See M. Hobday, "East versus Southeast Asian Innovation Systems: Comparing OEM-and TNC-led Growth in Electronics," in L. Kim and R.R. Nelson, eds., *Technology, Learning, and Innovation: Experiences of Newly Industrializing Economies* (Cambridge: Cambridge University Press, 2000), pp. 129-169.
 22. The intellectual precursors of NIS are C. Freeman, *Technology Policy and Economic Performance: Lessons from Japan* (London: Pinter, 1987); B.-Å. Lundvall, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (London: Pinter, 1992); R.R. Nelson, ed., *National Innovation Systems: A Comparative Study* (New York, NY: Oxford University Press, 1993). While Freeman uses the term "national system of innovation," Nelson, Lundvall, and others use the term "national innovation system" or NIS. We may use NIS and NSI, interchangeably, but for consistency I will use only NIS throughout this paper. Freeman was the first to systematically map out the analytical structure of a NIS based on empirical details of Japan's ascendance as one of the world's most dynamic economies through the "promotion of generic technologies," especially information and communication technology (ICT).
 23. R.R. Nelson, "National Innovation Systems," in Z. Acs, ed., *Regional Innovation, Knowledge and Global Change* (London: Pinter, 2000), pp. 11-26.
 24. See Freeman, op. cit., p. 1.
 25. Nelson (2000), op. cit.
 26. P.K. Wong, *National Innovation System: The Case of Singapore* (Seoul: Science and Technology Policy Institute, 1995): 5.
 27. Wong, op. cit., p. 9.
 28. See K.S. Goh, *Wealth of East Asian Nations: Speeches and Writings*, arranged and edited by L. Low (Singapore: Federal Publications, 1995).
 29. Goh, op. cit., p. 23.
 30. Huff, op. cit.

31. "Post-industrial" is meant in the sense of the progressively declining role of manufacturing output in GDP in favor of services and the declining numbers in blue-collar employment in favor of white-collar employment. The rise of knowledge and financial capital and the decline of industrial capital is another hallmark of post-industrialism. The three pioneering thinkers of post-industrialism are Bell, Touraine, and Drucker. D. Bell, *The Coming of Post-Industrial Society* (New York, NY: Basic Books, 1973); A. Touraine, *La société post-industriale* (Paris: Denoel, 1969); P. Drucker, *The Age of Discontinuity* (New York, NY: Harper & Row, 1969); P. Drucker, *Post-Capitalist Society* (New York, NY: HarperBusiness, 1993). Some of the contemporary thinkers are: M. Castells, *The Rise of the Network Society* (Malden, MA: Blackwell Publishers, 1996); A. Burton-Jones, *Knowledge Capitalism: Business, Work, and Learning in the New Economy* (New York, NY: Oxford University Press, 1999); N. Stehr, *Knowledge Societies* (London: Sage, 1994).
32. Wong (2001), *op. cit.*, p. 550.
33. In the case of Singapore (or, for that matter, any country) it is unreasonable to expect the emergence of fully autonomous entities of equal size (three intersecting circles of equal size) called for by the triple helix proponents.
34. The former Singapore Prime Minister Goh Chok Tong quoted in the *Singapore Enterprise*, April 2000 issue, is available at www.spring.gov.sg/news/enterprise/Apr/productivity.html_friendly.html, accessed April 16, 2002. According to Mr. Goh, "We want a spirit of enterprise, where trying, learning, and improving is a way of life; where everyone seeks to create value to have the extra edge. Singapore will then be a place where embracing change and creating value become instinctive."
35. Economic Review Committee, *op. cit.*
36. See Etzkowitz and Leydesdorff (2000), *op. cit.*
37. See EDB web site www.sedb.com/edbcorp/detailed.jsp?artid=2870&typeid=7, accessed February 16, 2002)
38. Some of the key steps undertaken by the government in the past few years to further the new innovation milieu involved creating: twelve research institutes under the A*STAR; an A*STAR R&D Assistance Scheme operated through its two research councils; a reorganized Productivity and Standards Board (PSB) now known as the Standards, Productivity, Innovation and Growth (SPRING) Board; the SPRING Board National Patent Information Centre; the Patent Application Fund; an Innovation Strategic Unit within EDB and the introduction of an Innovation Development Scheme to disburse financial assistance to encourage innovation; the Startup Enterprise Development Scheme (SEEDS) to provide equity financing for enterprise formation; the Local Industry Upgrading Program to foster closer business ties between local companies and foreign MNC partners; the Singapore Innovation Award; the revamping of Quality Circles to Innovation and Quality Circles (IQCs); the Incubator Support Scheme; and the Innovator's Assistance Scheme.
39. A.L. Chang, "Biotech Buzz at the Singapore Science Park," *The Straits Times*, Singapore, October 19, 2002, p. H21.
40. Sandra Davie and Jane Ng, "Universities to Get a Freer Hand," *The Straits Times*, February 12, 2004, p. 1.
41. The Sydney-based University of New South Wales is slated to open its Singapore campus in 2007.
42. Quoted in the remarks by Dr. Tony Tan, Deputy Prime Minister, at a Nanyang Technological University function held at the Istana, Singapore, on Wednesday, February 11, 2004
43. For details of the SMA, see <http://web.mit.edu/sma/>, accessed October 24, 2002.
44. See the NUS Enterprise portal www.enterprise.nus.edu.sg/aboutus/index.html, accessed October 24, 2002.
45. See the NUS Silicon Valley College site www.nus.edu.sg/etpi/ncsv/intro.html, accessed October 24, 2002.
46. See www.nus.edu.sg/etpi/ncbv/intro.htm, accessed March 28, 2003.
47. See <http://nus.edu.sg/noc/ncs/intro.htm>, accessed August 26, 2003.
48. See www.nus.edu.sg/occ/pressrel/prcontent.php?id=020325, accessed August 26, 2003.
49. For an interesting analysis of a private university's entrepreneurial transformation, see M. Jacob, M. Lundqvist, and H. Hellsmark, "Entrepreneurial Transformations in the Swedish University System: The Case of Chalmers University of Technology," *Research Policy* 33 (2003): 1555-1568.

50. See A*STAR, *Year 2000 National Survey of R&D in Singapore* at <www.a-star.gov.sg/astar/pdf/Publication/R&D_Surveywebsite.pdf>, accessed April 16, 2002.
51. A.H. Amsden, T. Tschang, and A. Goto, "Do Foreign Companies Conduct R&D in Developing Countries? A New Approach to Analyzing the Level of R&D, with an Analysis of Singapore," ADB Institute Working Paper 14, Tokyo, ADB Institute, 2001.
52. This, in part, must be to take advantage of the Singapore Government's various schemes to subsidize R&D expenditures of local companies.
53. Definition of bio-medical sciences industry found on the web site of EDB, available at <www.sedb.com>, accessed April 15, 2002.
54. The other three pillars of the economy are electronics, chemicals, and engineering.
55. Singapore does have a thriving horticulture industry, but its share in the national output is negligible.
56. IAC members are listed at <www.a-star.edu.sg/astar/about/action/about_bmrc_council.do>, accessed August 3, 2004.
57. EDB press release of February 6, 2002 at <www.sedb.com/edbcorp/detailed.jsp?artid=2816&typeid=7>, accessed April 16, 2002.
58. See the A*STAR web site at <www.a-star.gov.sg/international_programmes.shtml>.
59. Institute of Molecular and Cell Biology absorbed the Institute of Molecular Agrobiolgy.
60. D. Uren, "Edison Liu Is Leading Asia's Life Science Charge," *Asia Inc*, July 2001, at <www.asia-inc.com/printarticle.php?articleID=1930>, accessed April 25, 2002.
61. Ai-Lien Chang, "Research-Friendly S'pore Luring the Best and Brightest," *The Straights Times*, Singapore, February 17, 2004, p. H8.
62. Ai-Lien Chang, "Cancer Expert Excited to Work in S'pore," *The Straights Times*, Singapore, August 13, 2004, p. H14.
63. Details in EDB/A*STAR press release of February 6, 2002 at <www.sedb.com/edbcorp/detailed.jsp?artid=2816&typeid=7>, accessed February 16, 2002.
64. M. Nirmala, "Life-Sciences Course a Hit at NUS, NTU," *The Straits Times*, Singapore, April 29, 2002. In order to build from scratch biomedical sciences at NTU, Singapore lured Professor Alex Law from Oxford University. See, Chang (2004), op. cit.
65. Chang (2002), op. cit.; Ai-Lien Chang, "Biomedical Research Hub Launched," *The Straights Times*, Singapore, October 30, 2003, p. H7.
66. See EDB Singapore newsroom at <www.sedb.com/edbcorp/browse.jsp?cat=45&type=2&parent=35&root=35>, accessed March 28, 2003.
67. See EDB press release at <www.sedb.com/edbcorp/newsroom.jsp>, accessed April 15, 2002.
68. Uren, op. cit.
69. Ibid.
70. Before moving to Singapore to join ES Cell, Dr. Colman was the research director of British biopharmaceutical company PPL Therapeutics, the commercial partner of Roslin Institute. Dr. Colman was a member of the Scottish team that cloned Dolly the sheep in 1996.
71. A.L. Chang, "\$70m Stem-Cell Funding May See Cure for Diabetes," *The Straits Times*, Singapore, September 14, 2002, p. H19.
72. EDB biomed site <www.sedb.com/edbcorp/detailed.jsp?artid=669&typeid=7>, accessed February 16, 2002.
73. For more on increasing returns behavior of firms in the knowledge-based economy, see W. Brian Arthur, *Increasing Returns and Path Dependence in the Economy* (Ann Arbor, MI: University of Michigan Press, 1994); W. Brian Arthur, "Increasing Returns and the New World of Business," in Dale Kneef, ed., *The Knowledge Economy* (Boston, MA: Butterworth-Heinemann, 1998), pp. 75-85.
74. *The Economist*, August 14, 2004, p. 54.
75. *Annual Report 2002/03*, EDB Singapore 2004 at <<http://sedb.com/edbcorp/sg>>, accessed March 28, 2003.
76. See, *The Straits Times*, Singapore, July 16, 2004, p. H10-H11.
77. *The Economist*, op. cit.
78. *Building a Nation: 25 Years of Achievement in Singapore's Shipping and Transport Industry*, Singapore, Al Hilal Publishers, 1990; EDB Industry Report, *The Maritime Industry*, Singapore July 1993; Singapore Shipping Association, "Singapore: A Global Hub and New Challenges," Singapore, SSA, 2001.
79. Porter, op. cit.; Furman et al., op. cit.
80. At a theoretical level, Porter's "diamond" and the NIS (and the triple helix) are not mutually exclusive frameworks to study innovation and competitiveness of nations. These two

- paradigms complement each other to understanding the economic dynamics of capitalism. While Porter's diamond is a prescriptive economic policy paradigm, NIS and triple helix are less prescriptive and more analytical techno-economic paradigms. Unlike the former, Porter's diamond is not a model of innovation as such.
81. *Annual R&D Survey of Singapore* at <www.a-star.gov.sg/astar/pdf/Publication/R&D_Survey-website.pdf>, accessed March 28, 2003.
 82. Agency for Science, Technology and Research, "National Survey of R&D in Singapore 2000," Singapore, October 2003.
 83. Chang (2004), op. cit.; A.L. Chang, "'Fisherman' Reels in Top Talent in Science," *The Straights Times*, Singapore, August 13, 2004, p. H14. Chang also notes that three out of four of the top researchers in the A*STAR research institutes are foreigners.
 84. Furman et al., op. cit.
 85. See Parayil, op. cit.
 86. It is important for the triple helix system to expand its agential repertoire so as to enable the innovation milieu or selection environment to include significant actors from civil society. L. Leydesdorff and H. Etzkowitz, "Conference Report: Can 'The Public' Be Considered as a Fourth Helix in University-Industry-Government Relations? report on the Fourth Triple Helix Conference 2002," *Science and Public Policy*, 30 (2003): 55-62. Leydesdorff and Etzkowitz are skeptical of the suggestion to theorize the public as the fourth helix. They argue that such action "narrows the public into another private sphere, rather than seeing civil society as the foundation of the enterprise of innovation." This argument, however, fails both the theoretical and empirical spirit of their epistemic model.
 87. Parayil, op. cit.
 88. Quoted in Chang (2004), op. cit.
 89. See T.E.D. Yeo, *From Silicon to Genes: Singapore's Challenge in the Creative Economy*, unpublished Honors Thesis, Information & Communications Management Program, National University of Singapore, May 2003.
 90. A. Saxenian, "Regional Networks and Innovation in Silicon Valley and Route 128," in Z. Acs, ed., *Regional Innovation, Knowledge and Global Change*, (London and New York, NY: Pinter, 2000), pp. 123-138.
 91. See P. Evans, *Embedded Autonomy: States and Industrial Transformation* (Princeton, NJ: Princeton University Press, 1995).
 92. Lee, op. cit., p. 689. Lee is, essentially, validating Alexander Gerschenkron's theory of late-comer industrialization. Alexander Gerschenkron, *Economic Backwardness in Historical Perspective* (Cambridge, MA: Belknap Press, 1962).
 93. Mathews and Cho, op. cit.
 94. The recent shift in cultural policy adopted by the Singapore Government appears to follow Richard Florida's prescription that in order to enhance economic growth, states and cities must enhance their "creative capital." Creative capital, according to Florida, is composed of three Ts—Technology, Talent, and Tolerance. Singapore appears to have made great strides in two Ts, technology and talent. So all it needs now is the third T, tolerance, which is composed of three indices—bohemian index, gay index, and melting pot index. Since Florida's prescription for tolerance does not emphasize unfettered freedom of thought and political pluralism, it is an easier pill to swallow for the state. Richard Florida, *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life*, (New York, NY: Basic Books, 2002).

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