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OECD Review of Innovation in Southeast Asia

Country Profile of Innovation: Singapore

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This draft prepared by the OECD Secretariat will be used in Part 2 of the report of the *OECD Review of Innovation in Southeast Asia* which consists of *Country Profiles*. It draws upon a country background note prepared by Poh-Kam Wong and Annette Singh (Entrepreneurship Centre, National University of Singapore). Full acknowledgements will be provided in the published report.

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COUNTRY PROFILE OF INNOVATION: SINGAPORE

PRELIMINARY DRAFT

1. As a relative late-comer to industrialization and technological development in the global economy, Singapore has made significant progress in developing its science, technology and innovation (STI) capability over the last 45 years since political independence. This success was initially based on evolving a national system of innovation that emphasized attracting and leveraging global multinational corporations (MNCs) to transfer increasingly advanced technological operations to Singapore, and developing infrastructure and human resources to absorb and exploit new technologies rapidly. In the last decade or so, however, the country has started to shift towards a more balanced approach, with increasing emphasis on developing indigenous R&D and innovation capability. While the government has played a significant 'developmental state' role in guiding S&T capability development as an integral part of its overall economic development strategy, the emergence of a more vibrant technology entrepreneurial community is likely to be critical to Singapore's continuing transition from technology adopter to innovator in the future.

1. Macroeconomic performance and framework conditions for innovation

1.1. Performance and structure of the economy

2. Among late-industrializing economies, Singapore has achieved one of the most impressive economic growth records in the last four decades since its political independence in 1965, averaging 7.7% GDP growth per annum over the 1960-2010 period (Table 1.1). Singapore's per capita GDP of US$46,900 in 2009 (on PPP basis) stands as the highest in Asia and is on par with the US (US$46,400) (World Competitiveness Online).

Table 1.1. Aggregate economic growth performance, 1960-2010

	% real growth p.a					
	1960-70	1970-80	1980-90	1990-2000	2000-05	2005-10
GDP at 2005 mkt prices	9.2	9.0	7.7	7.2	4.8	6.4
Labour productivity	n.a	4.3	4.8	3.4	2.6	-2.4[1]
	S$ at current prices					
GNI per capita[2]	1970	1980	1990	2000	2005	2010
	2,820	9,900	20,100	39,600	42,983	57,603

[1] 2005-2009.

[2] GNP per capita prior to 1997.

Source: Calculated from Yearbook of Statistics Singapore (various years), Economic Survey of Singapore (various years). Per capita GNI obtained from Singstat website http://www.singstat.gov.sg/stats/themes/economy/hist/gnp.html. Mid-year population estimate for 2000 obtained from Singstat website, http://www.singstat.gov.sg/FACT/KEYIND/keyind.html

3. The rapid economic growth of Singapore has been achieved through continuous industrial re-structuring and technological upgrading. In the first decade after independence, growth was led largely by labour-intensive manufacturing. In the two subsequent decades, it was propelled by the growth of increasingly technology-intensive manufacturing activities by foreign MNCs, with high-technology products contributing an increasing share of total value added. The development of Singapore into an increasingly important business, financial, transport, and communications services hub in the Asia-Pacific region has provided additional engines of growth since the 1980s (Table 1.2). Nevertheless, manufacturing has remained important to the economy, with its share of GDP remaining above 25 per cent for most years in the last two decades. Since the 1990s, knowledge-intensive services and manufacturing have become the key drivers of Singapore's economic growth.

Table 1.2. Singapore's GDP distribution by sectors, 1960-2010 (%)

Industry	1960	1970	1980	1990	2000	2005	2010[p]
Agriculture & Mining	3.9	2.7	1.5	0.4	0.1	0.1	0.04
Manufacturing	11.7	20.2	28.1	28.0	25.9	27.8	23.2
Utilities	2.4	2.6	2.1	1.9	1.7	1.8	1.6
Construction	3.5	6.8	6.2	5.4	6.0	3.9	4.7
Commerce	33.0	27.4	20.9	16.3	19.1	17.5	19.5
Transport & Communication	13.6	10.7	13.5	12.5	11.1	14.7	12.7
Financial & Business Services	14.4	16.7	18.9	25.5	25.3	23.4	27.1
Other Services	17.6	12.9	8.7	9.9	10.9	10.9	11.2
Total	100%	100%	100%	100%	100%	100%	100%

[p] Preliminary figures

Notes: Figures may not add up to 100 due to rounding.

Sources: Calculated from Department of Statistics, *Yearbook of Statistics Singapore*, various years; Ministry of Trade and Industry, *Economic Survey of Singapore*, various years.

4. Given its rather small domestic market, the Singaporean economy has been highly dependent on the external regional and global markets for growth. Indeed, a cornerstone of Singapore's public policy has been to promote openness to external trade and investment. This is reflected in the stock of inward FDI (foreign direct investment) in Singapore, which amounted to $470 billion in 2008 (triple the amount in 1998). The recipient sectors are relatively concentrated, with 40% in financial and insurance services and over one-fifth in manufacturing (Table 1.3). In terms of regions, the largest contributor to FDI in Singapore is Europe (41% in 2008), followed by Asia (23%, with Japan contributing 10.4%). US companies accounted for a similar amount of FDI in Singapore as Japanese companies. Singapore's regional neighbours account for only a small share of inward investment, with 3.6% of FDI coming from ASEAN countries.

Table 1.3. Stock of foreign direct investment In Singapore by industry, 1998 vs 2008

	1998	2008
Total stock of FDI in Singapore ($million)	144,197.2	470,315.9
	Percentage	
Manufacturing	36.0	22.7
Construction	1.0	0.3
Wholesale & Retail Trade	13.9	18.0
Hotels & Restaurants	0.7	0.7
Transport & Storage	3.6	7.5
Information & Communications	0.5	0.9
Financial & Insurance Services	37.4	39.8
Real Estate, Rental & Leasing	3.9	4.2
Professional & Technical, Administrative & Support Services	2.8	5.2
Others	0.1	0.5
Total	100.0	100.0

Source: Department of Statistics, Yearbook of Statistics Singapore 2010.

1.2. Framework conditions for innovation

5. Because of the high openness of the economy and the strong reliance on external market forces, local Singaporean firms are by and large highly exposed to global competitive market pressures, and the demand for quality that they transmit. In particular, the high presence of many leading 'world-class' global MNCs in Singapore itself contributes significantly to the articulation of demands for quality and process improvement in manufacturing and logistics services (Wong 2003). It is thus not a surprise that Singapore has developed among the best air- and sea-transport infrastructures and logistic support industries in the world: they had to innovate or risk losing customers to other regional competition.

6. The World Bank's benchmarking survey on the ease of doing business ranks Singapore first in the world out of 183 economies. It is also ranked by Transparency International as one of the least corrupt countries in the world. On the downside, land is scarce while labour often has to be imported to meet the skills demands of a knowledge-based economy.

2. Innovation performance

7. R&D in Singapore was minimal until the late 1980s, with a Gross Expenditure of R&D (GERD) to GDP ratio of only 0.86% in 1987, significantly below the levels of OECD countries. Since then, however, R&D investment intensity in Singapore has increased significantly, with the GERD/GDP reaching 2.3% in 2009, which is only slightly behind Germany (2.6%), Taiwan and the US (2.8%), although it still lags significantly behind Korea (3.4%) and some of the small advanced European countries such as Sweden and Finland (around 3.8%) (Table 2.1). Singapore faces a shortage of skilled R&D manpower and has endeavored to address this through a range of policies incorporating both education and attraction of foreign talent through immigration. Although the absolute number of research scientists and engineers (RSEs) has increased substantially, Singapore's technical human resource development may still have some way to go to catch up with other small advanced countries with similarly small domestic population bases. The number of researchers per 10,000 labor force in Singapore in 2008 (97) is lower not only than Korea and Taiwan, but also than in Finland, Sweden and Denmark (over 100 researchers per 10,000 labor force) (Wong and Singh 2008).

Table 2.1. R&D intensity and researchers in the labour force

	1996	2000	2005	2008	2009
GERD/GDP	1.4	1.9	2.3	2.8	2.3
Number of researchers per 10000 labour force	56	66	99	97	89

Source: National Survey of R&D in Singapore (various years), National Science & Technology Board (prior to 2001) and Agency for Science, Technology & Research (2001 to 2009)

8. Data on R&D expenditure in Singapore show that the private sector, government sector, and higher education sector all contributed to the rapid increase in R&D intensity (Table 2.2.). From the late 1970s, much of the R&D investments in Singapore have been performed by the private sector. The share of private sector R&D in total GERD grew significantly from the mid-1980s to mid-2000. The R&D intensity in the private sector has hovered at around two-thirds since 2005 (with some fluctuations in more recent years), with the balance more or less split evenly between the three sectors of public R&D: higher education, public research institutes and various government sectors.

Table 2.2. R&D expenditure by sectors, 1978-2009

Year	Private Sector	Higher Education Sector	Government Sector Percentage	Public Research Institutes	Total
1978	67.5	21.7	10.8	na	100.0
1984	49.8	32.5	17.7	na	100.0
1990	54.1	20.9	17.4	7.5	100.0
1995	64.5	14.2	8.1	13.3	100.0
2000	62.0	11.2	14.1	12.7	100.0
2005	66.2	10.4	9.7	13.8	100.0
2006	65.7	11.5	10.3	12.4	100.0
2007	66.8	9.5	12.2	11.5	100.0
2008	71.8	10.0	7.6	10.6	100.0
2009	61.6	14.1	11.3	12.9	100.0

Source: National Survey of R&D Expenditure and Manpower (various years), Science Council of Singapore (prior to 1990); National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990-2000) and Agency for Science, Technology & Research (2001 to 2009)

9. R&D in both the public and private sectors of Singapore has traditionally been concentrated in incremental, applied work (Table 2.3). Basic R&D only began to receive increasing share of total R&D spending in Singapore from 2001, rising to 20.3% in 2009. The shift in focus to a more basic, strategic, and longer-term R&D from the late 1990s is reflected in the national S&T policy in the 2000s (see below).

Table 2.3. R&D expenditure in Singapore by type of R&D 1993-2009

	1993	1997	2000	2005	2006	2007	2008	2009
	Percentage breakdown of R&D exp (%)							
Basic research	16.1	12.8	11.8	21	20.6	17.4	17.0	20.3
Applied research	39.1	43.8	35.0	33	31.9	24.7	25.3	32.5
Experimental development	44.9	43.3	53.2	47	47.4	57.9	57.7	47.2

Source: National Survey of R&D Expenditure and Manpower (various years), Science Council of Singapore (prior to 1990); National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990-2000) and Agency for Science, Technology & Research (2001 to 2009).

10. Table 2.4. shows that the number of publications produced by Singapore over 2000-2010 (589,400) is about the same as Ireland, though lower than for Taiwan and Korea as well as the advanced small European countries of Sweden and Finland. However, the citations received per paper for Singapore (9.4) is slightly higher than for the other two NIEs (7.1), although still lower than for the European countries (12 or higher). On the other hand, Singapore's output of scientific publications has been growing fairly rapidly. Data on scientific publications from the WCY revealed that the growth of Singapore publications between 1997-2007 (11.0%) is comparable to Korea (12.3%) and higher than in Taiwan (7.8%) and the small European countries of Ireland, Finland and Sweden.

Table 2.4. Quantity and quality of publications, 2000-2010

	No. of papers	No. of citations	Citations Per Paper
Singapore	62,947	589,433	9.4
Taiwan	169,555	1,195,634	7.1
Korea	266,682	1,892,966	7.1
Ireland	43,668	503,196	11.5
Sweden	180,269	2,702,126	15.0
Finland	89,436	1,244,315	13.9
China	762,098	4,578,689	6.0
US	3,069,500	49,593,619	16.2

Note: Includes Thomson Scientific-indexed journal articles only.

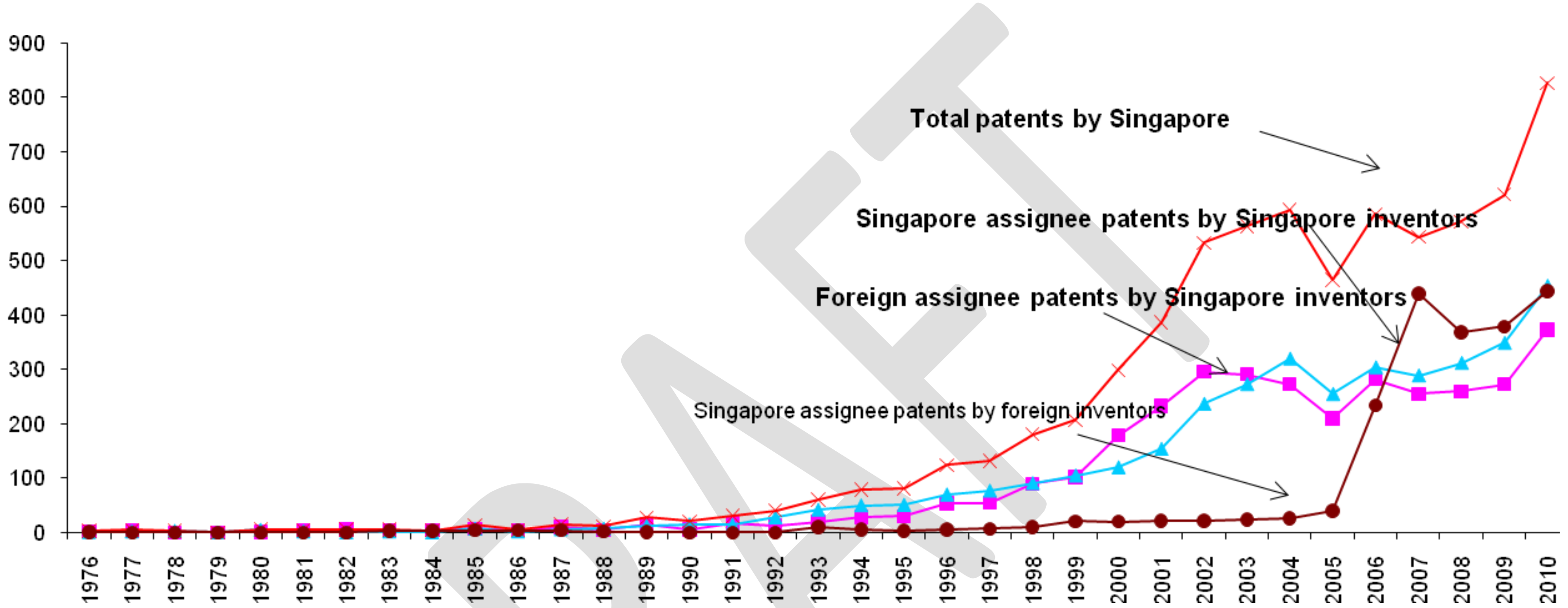
Source: Essential Science Indicators.

11. The absolute number of Singapore-based patents is still low, totaling 7,063 patents granted by the USPTO (US Patent and Trademark Office) as of 2010 (Figure 2.1), although its patenting performance has improved significantly over the last 10 years. The cumulative number of USPTO-granted patents to Singapore-based inventors was only 427 up to 1995. This more than tripled to 1370 by the end of 2000, and in the recent decade 2001-10, another 5693 were granted, i.e. 80% of the total cumulative number of US patents granted have been in the last 10 years.

12. Until 2000, foreign companies accounted for more than half of all US patents granted to Singapore-based inventions, reflecting the dependence of Singapore on R&D by foreign MNCs. However from 2000 to 2003, patents assigned to Singapore companies outnumbered those assigned to foreign companies, reflecting the growth in indigenous innovation capabilities in both the public sector and the local private sector, including the emergence of local high-tech start-ups (Wong and Singh 2008). Nevertheless, from 2004, patents assigned to foreign companies once again outnumbered those to local companies, suggesting the growing importance of Singapore as a regional R&D hub for MNCs.

13. Singapore ranked fourth in patenting propensity amongst the Asia-Pacific economies in 2009, producing 134 US patents per million people, an increase from 105 patents in 2005. Its domestic ownership of patenting (44.4% for 2006-2009) is substantially lower than Korea (94.2%) and Taiwan (74.7%), which both have much stronger indigenous STI (science, technology and innovation) capabilities in their local industries. Singapore's share of domestically owned patents is also slightly lower than Hong Kong (47.1%) but higher than for China (36.1%) and India (29.9%).

Figure 2.1. Growth in Singapore patents issued by the USPTO, 1976-2010



	1976-1985	1986-1995	1996-2000	2001-2005	2006-10	Total
Patents by Singapore Inventors						
Singapore Assignee	30	148	480	1303	1443	3404
Foreign Assignee	22	227	463	1239	1708	3659
Total	*52*	*375*	*943*	*2542*	*3151*	*7063*
Patents by Foreign Inventors Assigned to Singaporean Organizations						
	11	30	64	134	1865	2104
Total	***63***	***405***	***1007***	***2676***	***5016***	***9167***

Source: compiled from NUS Entrepreneurship Centre's Singapore Inventor Database of the U.S. Patent and Trademark Office (USPTO).

3. Innovation policy: institutional framework and policy orientations

3.1. Historical development of innovation policy

14. Singapore's openness to external markets does not mean that the state plays no role in shaping the formation of new markets; unlike the largely laissez faire, hands-off role of the state in Hong Kong (Sharif and Baark 2008), the Singaporean state has pursued an active, opportunistic role in identifying new market trends that have emerged, and in quickly devising policy incentives and investing in supporting infrastructures and resources to attract global players that are well placed to capitalize on these new market development trends to locate part of their activities in Singapore, thereby allowing Singapore to reap an 'early-entry' advantage.

15. Singapore's first significant policy recognition of the economic importance of R&D came in 1989 when a Committee of Ministers of State was formed to outline the long-term strategy and direction of Singapore's development. The result was a 'vision' document called 'The Next Lap', which highlighted the need to focus on R&D and specialize in high-tech niches in order for Singapore to catch up with the advanced countries over the next 20 years (Government of Singapore, 1991). Two years later, the first five-year National Technology Plan (NTP) was released. The key objectives of the NTP were to promote industrially relevant R&D, build up S&T human resources, and develop an S&T support infrastructure. A new statutory board, the National Science and Technology Board (NSTB) was simultaneously established to implement the NTP. To this end, a $2 billion allocation was given to NSTB. A key outcome of the NTP was the establishment of a series of PRIs, which were to be funded and managed by NSTB. This was done through a combination of creating *de novo* institutes, as well as re-organizing and transferring a number of existing research institutes from the Higher Education and Government sectors. The NTP was followed by the formulation of a second five year plan in 1996, called the second National Science and Technology Plan (NSTP), where the budget allocation was doubled to $4 billion, and where the importance of investing in science was recognized in addition to technology. Despite this recognition of the importance of science, the NSTP was still heavily skewed towards applied R&D promotion rather than basic research. Indeed, the initial mission of most of the PRIs established under the NTP was to develop the applied technologies deemed critical for Singapore's industrial clusters (Wong 2003), and this applied focus continued into the late 1990s.

16. The late 1990s however, saw a drastic shift in Singapore's S&T policy direction. The Asian Financial Crisis in mid-1997, which led to a severe regional economic downturn, raised concerns about the need to diversify markets and achieve greater penetration of European and North American markets. This clearly required Singapore to have a higher technological competitive edge. In addition, growing competition from China and India meant that Singapore would be subject to severe cost pressures. Finally, the leadership had become increasingly impressed by the Silicon Valley model of high-tech innovation (including the successful Israeli and Taiwanese variants) as key to success in the global knowledge-based economy. All these factors motivated the government to launch a new economic development program called the Technopreneurship21 (T21) initiative in 1999. However, with the bursting of the Internet bubble in 2000, policy makers realized the need for start-ups to have truly innovative technologies and defensible intellectual property, and hence the need to raise basic research and innovative capabilities. At the same time, the government recognized the need to make a big push into life sciences.

17. Accordingly, the NSTB was restructured in 2001 and re-named the Agency for Science, Technology and Research (A*STAR). It was re-focused on developing Singapore's R&D capabilities, particularly the attraction and training of R&D workforce. At the same time, the NSTB's former role of nurturing technopreneurship was transferred to the Economic Development Board (EDB). Planned public spending on S&T was also increased to $7 billion

in the Third Science & Technology Plan for 2001-2005 (NSTP 2005), with $5 billion allocated to A*STAR to fund public research and to develop postgraduate research personnel while the remaining $2 billion was managed by EDB to support R&D in the private sector. The Plan also allocated a larger proportion of the public R&D budget to long-term strategic and basic research (Wong 2003, A*STAR 2001).

18. This shift in emphasis towards building long-term basic research capabilities further intensified in 2006, with a budget of $13.55 billion for R&D over five years planned in the National Science & Technology Plan 2010 (STP 2010) and with the establishment of the National Research Foundation (NRF) (Wong 2011). The current 2011 to 2015 R&D Budget of $16.1 billion represents a 20% increase over STP2010; moreover greater emphasis will be placed on technology commercialization in order to recoup economic returns from R&D, including encouraging public-private R&D partnerships, technology transfer offices and enterprise incubators (Teh 2010).

3.2. Main innovation policy actors

19. A characteristic feature of Singapore's approach to S&T policy implementation is the relatively top-down approach to technology policy formulation that is strategic in nature, yet flexible in terms of actual implementation. Indeed, Schein (1996) had described this approach of Singapore policy making as 'strategic pragmatism'; although his work was focused on the EDB alone, much of what he found appears to be applicable to the S&T policy arena in general. In essence, Singapore's political leaders at the Cabinet level formulate broad, long-term strategic economic development initiatives, but delegate much of the detailed implementation to the designated implementation agencies. Moreover, the government has been quite prepared to revise substantially an earlier strategic plan and replace it with a newer one, if and when it perceives the environmental opportunities or threats have changed materially. This change in strategic direction is typically not due to changes in specific political leadership, since the government has been under a one-party rule since political independence in 1965.

20. One consequence of this top-down approach is that S&T policy is typically not formulated in isolation, but as an integral part of a larger economic development strategy. This 'developmental state' approach has meant that S&T policies are strongly integrated within ministries with significant economic development roles, particularly the Ministry of Trade and Industry (MTI), and the Ministry of Information, Communications and the Arts (MICA). Indeed, it is telling that, until today, Singapore does not have a separate Ministry of Science and Technology; instead, these policy-making and implementation functions have been subsumed by the economic development oriented ministries. Thus, A*STAR comes under MTI, while IDA (Infocomm Development Authority of Singapore), which promotes ICT deployment, comes under MICA.

21. An outline of the prevailing institutional framework for S&T policy in Singapore is shown in Figure 3.1. Of particular note is the RIEC (Research, Innovation and Enterprise Council) established in 2006 and chaired by the Prime Minister. This is intended to strengthen coordination of different programmes and initiatives by different ministries and agencies. The NRF was established as a department in the Prime Minister's Office to support the RIEC and to implement national research, innovation and enterprise strategies approved by the RIEC. As such, NRF oversees the strategic overview of national R&D of Singapore (Yeo 2006). To this end, NRF is responsible for developing policies, plans and strategies for research, innovation and enterprise; funding strategic initiatives; building up Singapore's R&D capabilities and capacities through nurturing local and attracting foreign talent; and coordinating the research agenda of different agencies. A five-year budget of $5 billion has been allocated to the NRF to achieve its mission. Through the NRF, the Singapore government is undertaking a fairly holistic approach to the development of indigenous

capabilities in the Singapore NIS; over and above the financing of R&D, NRF's task includes developing linkages between actors in the NIS and facilitating technology commercialization and the growth of high-tech startups (Wong and Singh 2011).

22. Furthermore, $1.55 billion has been allocated to NRF for the development of three strategic sectors in which Singapore is seen to have a competitive advantage and are critical for future economic growth, namely:

1. Biomedical sciences (BMS) – focusing on building on Singapore's basic R&D discovery capabilities to translate basic science into better medicines and treatments to improve patient care.
2. Environmental and water technologies (EWT) including clean energy – leveraging on Singapore's foundation in water technologies and management and its competitive advantages in other environmental technology sectors. This is complemented by the clean energy initiative which will focus on solar and fuel cells, in which Singapore also has a competitive advantage. Being a compact city state, Singapore is also an ideal test-bed for new technologies in these areas.
3. Interactive and digital media (IDM) – building on Singapore's multi-cultural, multi-lingual identity and its strong ICT infrastructure to create new innovative niches in IDM including animation, games & effects, education and edutainment, "on-the-move" media services and media intermediary services.

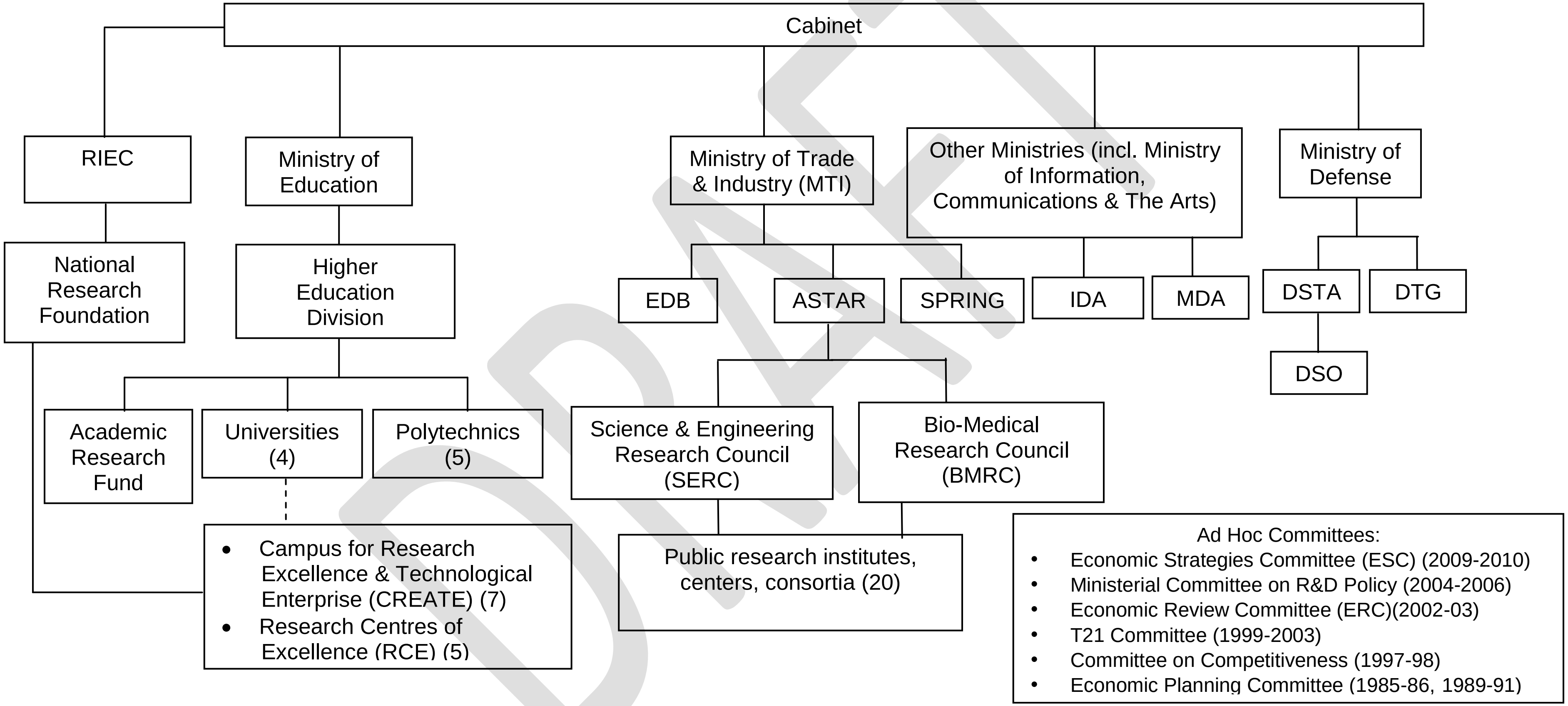
23. Attention will be given to commercial development, bringing scientific knowledge from the lab to the market. It is targeted that these sectors will provide a total of 86,000 jobs with value added of $30 billion by 2015, underscoring the government's aim for R&D efforts to result in economic benefits rather being undertaken for the sake of the development of science and technology per se (Wong and Singh 2011).

24. On other significant actors, the Ministry of Education oversees the three public universities and five polytechnics in Singapore. The Academic Research Fund (AcRF) under MOE was established in 1994 to support academic research in the Singapore universities. Starting with a budget of $96 million in the earlier years, the AcRF has increased to approximately $250 million per year in 2010s (Wong 2011, MOE website).

25. The Ministry of Trade and Industry (MTI) is responsible for coordinating science and technology policies, and formulating key economic policies for the country. The key statutory boards under MTI implementing STI policies are EDB, A*STAR and the Standards, Productivity and Innovation Board (SPRING).

- EDB is Singapore's lead government agency for the promotion of inward foreign direct investments and knowledge-based industries. It is responsible for raising the level of private sector R&D by attracting more multi-national companies to locate corporate R&D activities in Singapore (Wong 2011).
- A*STAR is responsible for the development of indigenous R&D capabilities, including overseeing the PRIs. To achieve its mission, it set up two councils: the Bio-Medical Research Council (BMRC), responsible for promoting R&D and developing human capital in the life sciences, and the Science and Engineering Research Council (SERC), which does the same in targeted science and engineering clusters such as ICT, chemicals and engineering clusters. In total, A*STAR oversees 21 research institutes, centers and consortia.
- SPRING promotes innovation among SMEs. As such, SPRING is responsible for administering a number of innovation financing schemes targeting the development of technologically weak SMEs, as well as the cultivation of entrepreneurship in Singapore.

Figure 3.1. Emerging institutional framework for S&T policy in Singapore as of 2011



EDB – Economic Development Board
ASTAR – Agency for Science, Technology & Research
SPRING – Standards, Productivity and Innovation Board
IDA – Infocomm Development Authority
MDA – Media Development Authority
DSTA – Defence Science & Technology Administration
DTG – Defence Technology Group
DSO – Defence Science Organisation
RIEC - Research, Innovation and Enterprise Council

4. Actors of the national innovation system

4.1. Business sector

26. Singapore's BERD reached $3.8 billion, or 61.6% of GERD in 2009. Manufacturing firms constituted the lion's share of R&D spending, peaking at 88% of total private sector R&D in 1996 before declining somewhat to 62.2% by 2009 (Table 4.1). Manufacturing R&D remains highly concentrated in a number of sectors, with two-thirds in the electronics sector alone in 2009, followed by engineering (19.4%). This is consistent with the fact that electronics and IT have been the most important and dynamic sectors in the Singapore economy since the 1980s, which in turn stimulated a certain amount of R&D in the precision engineering industry (Wong 2003). Private sector R&D in life sciences remains small (3.6%). There has also been a noticeable increase in the share of private sector R&D going to services sector in the early 2000s, reflecting the growing sophistication of Singapore's KIBS. In particular, IT & communications services have been major contributors to service R&D.

Table 4.1. Distribution of private sector R&D expenditure by industry, 1993-2009 (%)

	1993	1998	2005	2009
PRIMARY INDUSTRIES & CONSTRUCTION	**na**	**na**	**0.1**	**0.1**
MANUFACTURING	**81.1**	**86.9**	**65.2**	**62.2**
Electronics	51.4	48.3	39	41.8
Chemicals	5.6	10.8	4.7	2.1
Engineering	16.8	22.7	10.6	12.1
Precision Engineering	11.2	19.2	8.1	7.8
Process Engineering	1.2	0.6	na	na
Transport Engineering	4.3	2.9	2.5	4.2
Life sciences	4.0	4.2	3.0	3.6
Light Industries/Other Manufacturing	3.4	1.0	7.9	2.7
SERVICES	**18.9**	**13.1**	**34.8**	**37.8**
R&D	na	na	10.9	14.6
IT and Communications[1]	3.2	9.2	4.9	3.7
Finance & Business	4.3	1.4	8.6	1.1
Other Services	11.3	2.5	10.3	8.5
ALL INDUSTRY GROUPS	***100.00***	***100.0***	***100.0***	***100.0***

[1] Part of ICT has been re-classified as belonging to 'other services' since 2001

Source: National Survey of R&D Expenditure and Manpower (various years), Science Council of Singapore (prior to 1990); National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990-2000) and Agency for Science, Technology & Research (2001 to 2009)

27. Table 4.2 shows the extensive role played by foreign firms in Singapore. Foreign firms comprised 16% of the number of enterprises, contributing almost one-third of employment and half of value added in 2008. Amongst the high-tech sectors, the dependence on foreign firms was even higher: almost one-quarter of the total number of enterprises, accounting for 40% of employment and 61% of value added. In the high-tech manufacturing sector, in which many of the MNCs are operating, the contribution of foreign firms is higher still: although they only comprise 13.7% of the number of enterprises, they account for 42.3% of employment and 70% of value added. Foreign firms also account for a larger proportion of R&D activities in Singapore than local firms; in 2009, MNCs accounted for almost three-quarters of private R&D expenditure (Table 4.3).

Table 4.2. Profile of high-tech vs non-high-tech sectors in Singapore, 2008

	High-Tech Sectors			All Sectors		
	Total	% Local	% Foreign	Total	% Local	% Foreign
Establishments	13,137	77.0	23.0	158,796	83.7	16.3
Employment	426,143	60.3	39.7	1,788,913	70.6	29.4
Value Added	$52.9 bn	39.1	60.9	$205.1 bn	50.8	49.2
	High-Tech Manufacturing Sectors			**All Manufacturing Sectors**		
	Total	**% Local**	**% Foreign**	**Total**	**% Local**	**% Foreign**
Establishments	3,597	86.3	13.7	8,640	84.0	16.0
Employment	308,769	57.7	42.3	435,154	62.3	37.7
Value Added	$39.1 bn	30.2	69.8	$47.2 bn	36.0	64.0
	High-Tech Services Sectors			**All Service Sectors**		
	Total	**% Local**	**% Foreign**	**Total**	**% Local**	**% Foreign**
Establishments	9,540	73.5	26.5	149,822	83.7	16.3
Employment	117,374	67.2	32.8	1,351,605	73.3	26.7
Value Added	$13.8 bn	64.5	35.5	$157.8 bn	55.2	44.8

[1] High-tech manufacturing comprises: coke and chemical products, rubber & plastics, machinery & equipment, electrical & electronics products, precision instruments and transport equipment. High-tech services comprises ICT services, architectural and engineering activities, technical testing and R&D

Source: Wong, Ho and Singh (2011), based on unpublished data compiled from Singapore Department of Statistics

Table 4.3. Foreign companies' share of industry R&D expenditure, 1996-2009

	1996	2001	2005	2009
	Foreign firms' share of private sector R&D (%)			
MANUFACTURING	69.1	61.9	72.2	77.9
Biomedical sciences	71.6	59.6	97.5	92.2
Electronics	68.8	67.6	66.9	84.4
Chemicals	90.9	74.5	89.4	83.5
Engineering	51.1	37.9	63.0	62.9
General manufacturing	12.7	17.9	91.3	20.7
SERVICES	51.8	41.1	57.0	64.3
R&D	na	na	54.8	62.1
IT and Communications[1]	54.7	43.6	31.2	40.5
Logistics	na	na	0.1	14.3
Finance & Business [2]	67.1	46.9	48.6	66.6
Other Services	16.2	36.9	80.4	80.3
ALL INDUSTRY GROUPS	67.0	57.6	66.8	72.7

[1] Post & telecommunications; IT and related services

[2] Financial intermediation and other business activities

Source: National Survey of R&D Expenditure and Manpower (various years), Science Council of Singapore (prior to 1990); National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990-2000) and Agency for Science, Technology & Research (2001 to 2009)

28. Among the local firms that engage in R&D activities, three different groups can be distinguished. The first group consists of the more technically advanced small and medium-sized enterprises operating in

the various supporting industries supplying to MNCs, particularly precision engineering. Good examples include Amtek (metal stamping), Spindex (precision engineering), Meiban (precision plastic moulding), Gul technology (printed/flexible circuit board), and Venture Manufacturing and JIT (contract manufacturing). The major focus of their technical efforts is in improving their manufacturing process capability to meet the stringent quality, cost and delivery demand of their large MNC customers, although a small number of these firms have also started to diversify into own product innovation activities (Wong 2003).

29. The second group consists of the various state-controlled enterprises established by the Singapore government with the specific aim to spearhead local participation in high-tech industries. Called government-linked companies (GLCs), these companies have strong financial backing from holding companies established by the government and hence have been able to commit significant investment in innovation activities. Among the more significant players include the companies within the Singapore Technology (ST) Engineering Group, Sembawang Group, Keppel Group and Natsteel Group. The ST Engineering Group, for example, has subsidiaries that are engaged in aerospace repair/maintenance engineering (ST Aerospace), semiconductor fabrication (Chartered Semiconductor Manufacturing), electronics systems integration (ST Electronics) and computer software systems (SCS). Both Keppel and Sembawang started as shipyards, but had since become diversified conglomerates; at the same time, their core shipbuilding and repairing operations had been transformed to become global leaders in offshore rig-building. The Natsteel group started as a national steel manufacturer, but has since diversified into electronics contract manufacturing (Natsteel Electronics (later acquired by Solectron) and Natsteel Broadway), and its steel operations were acquired by the Tata Group in 2004.

30. The third and last group of local enterprises consists of a small but rapidly increasing number of entrepreneurial high-tech start-up firms that seek to pioneer innovative products through their own R&D and brand development. The first wave of such firms in the late 1980 and early 1990s include PC firms like IPC and GES, audio-cards firms like Creative and Aztech, industrial electronics firms like Powermatics and Teledata, machine tools makers and industrial machinery makers such as Excel Machine Tools and Falmac, and software companies like CSA and Systems Access. However, despite achieving some early success, including listing on the local stock exchange, many of these early independent high tech start-ups either failed (e.g. Excel) or exited (IPC) or became absorbed by larger firms (e.g. both CSA and Systems Access have been acquired by larger American software firms) by the early and mid-2000s. From the late 1990s to early 2000s, a second wave of new start-ups has emerged, mainly related to internet/e-commerce as part of the dotcom boom. Most of these also died in the ensuing dotcom crash. From the mid-2000s, a third wave of high-tech start-ups has emerged. Unlike the first wave of local start-ups where the founders typically came from having worked in industries (especially MNCs), the new wave of entrepreneurs tend to come more from tertiary institutions and public R&D institutions, and are increasingly being funded by venture capital firms and an emerging angel investment community. These include companies founded by university professors (e.g. Semicaps, an IC failure analysis equipment maker founded by a professor from the National University of Singapore (NUS), researchers at public research institutes (e.g. Muvee, a video editing software technology spin-off from I2R), and university students (e.g. tenCube, a mobile security company founded by NUS students, recently acquired by McAfee).

4.2. Higher Education Institutes (HEIs)

31. Prior to the establishment of the public research institutes (PRIs), public sector R&D was focused in the higher education sector. HERD accounted for almost one-third of GERD in the mid-1980s. Subsequent to the formation of the PRIs, HERD's share of GERD almost halved to 15.8% in 1995. Although the absolute amount of R&D expenditure in the higher education sector continued to rise, from $193.4 million in 1995 to $338.3 million in 2000, to $478.0 million in 2005, HERD's share of GERD continued to fall 11.2% in 2000 to 10.4% in 2005. In recent years, however, the higher education sector's

share of national R&D expenditure rose again, with HERD reaching $854.3 million in 2009 (14.1% of GERD). The shift towards basic research with the implementation of recent government strategic plans is also evident, with expenditure on basic research in the HE sector increasing from $115.1 million (34% of HERD) in 2000 to $462.4 million (54.1% of HERD) in 2009 (Table 4.4).

Table 4.4. Higher education sector R&D expenditure and manpower, 1995-2009

Year	Total R&D Expenditure ($ million)	RSEs (FTE)	Basic R&D Expenditure ($million)	% share of HE Basic R&D Expenditure
1995	193.4 (15.8)	1543.8 (18.5)	67.2	34.7
2000	338.3 (11.2)	1741.3 (15.4)	115.1	34.0
2005	478.0 (10.4)	2418.9 (36.7)	254.5	53.2
2009	854.3 (14.1)	4365.6 (19.0)	462.4	54.1

Note: Figure in brackets is percentage of national total.

Source: National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990-2000) and Agency for Science, Technology & Research (2001 to 2009).

32. Singapore has a well-developed tertiary education system, incorporating universities, polytechnics which were set up with the mission to train middle-level professionals to support the technological and economic development of Singapore, and a network of ITEs (Institute for Technical Education) with a host of industrially relevant vocational training programs (Wong 2003, MOE website). There are currently three universities, two of which are public (the National University of Singapore (NUS) and the Nanyang Technological University (NTU)) and one private (Singapore Management University (SMU)). A fourth university, the Singapore University of Technology and Design (SUTD), which will involve collaboration with MIT and Zhejiang University, will commence classes in 2012. There are also currently five polytechnics and three ITEs. In addition, the Singapore government has actively attracted several leading universities to operate branch campuses in Singapore (Olds, 2007), including INSEAD, University of Chicago Business School, James Cook University, and the New York TischAsia School of the Arts. There are also a large number of part-time tertiary diploma and degree programs operated in Singapore by various overseas universities on a distance learning basis, although most of these programmes concentrate on non-technical fields; the aggregate number of technical graduates from these private programs is still relatively small and confined largely to IT-related fields.

33. NUS has the highest number of publications among the local universities (173.2 per 100 faculty vs. 139.6 per 100 faculty for NTU and 36.4 per 100 faculty for SMU). NUS' publication output per faculty compares favorably with the regional universities, being on par with Japan's Kyushu University (170.8 per 100 faculty), and somewhat higher than Tohoku and Tokyo University as well as China's Tsinghua University and Mahidol University (Thailand) and Multimedia University (Malaysia) (MMU), although it was out-performed by Hong Kong University of Science & Technology (HKUST), National Taiwan University and the Korean Advanced Institute of S&T (KAIST). NTU's publication per faculty is somewhat less than for Tsinghua University, while SMU's is on par with MMU. In terms of quality of papers, NUS, with 10.6 citations per paper between 2000 and 2010 is outperformed by Tokyo University (15.1 citations per paper), but is generally on par with the other Japanese universities and HKUST. NTU, with 6.7 citations per paper for the same period, falls lower in the comparison with the other universities, being comparable with Tsinghua University.

34. A total of 316 US-issued patents have been granted to Singapore universities, which amounts to 5.2% of the national total. Of these, the majority come from the NUS (total of 266 patents, or 4.3% of the national total). Patenting is a relatively recent activity of the universities with the bulk (87%) issued since 2000. This reflects in large part the government's emphasis on universities 'third mission', where increasing prominence has been given since the early 2000s to their role in stimulating economic growth

through industrially-relevant research, technology commercialization, high-tech spin-offs, attraction of foreign talent and injecting an entrepreneurial mindset among their graduates. Among the local universities, NUS has made the most efforts in fulfilling these roles. In 2001, NUS created a new division in the university called NUS Enterprise to spearhead the pursuit of activities to make NUS entrepreneurial. Under the broad mission to inject a more entrepreneurial dimension to NUS education and research, the CEO was tasked to make the division the primary organizational vehicle for coordinating and managing all major university activities related to technology commercialization and entrepreneurship promotion within NUS (Wong, Ho and Singh, 2007).

4.3. Public Research Organisations (PROs)

35. The main group of public research organisations (PROs) in Singapore are the PRIs managed by A*STAR. In addition to these, STI activities are carried out in the various other government agencies. In total, the PRO sector (PRIs and government sector) accounted for $1.5 billion of GERD in 2009 (24.2% of the national total), just over half of which ($780.9 million) was accounted for by the A*STAR PRIs (Table 4.5). In terms of S&T manpower, the PROs employed 4,460 RSEs (FTE), or 19.4% of the national total, in 2009, of which 60.5% (2,700 RSEs) are in the PRIs. The PROs have generally been performing about one-quarter of the R&D in Singapore over the last decade (about 13% for the PRIs specifically), and employing about one-fifth of the RSEs in Singapore since 2005 (down from about one-quarter in 2000) (around 12% for the PRIs).

Table 4.5. Public Research Organizations sector R&D expenditure and manpower, 2000-2009

Year		1995	2000	2005	2009
Total R&D Expenditure ($ million)	Govt+PRI	291.8 (21.4)	805.2 (26.8)	1072.9 (23.4)	1464 (24.2)
	PRI	181.4 (13.3)	381.4 (12.7)	630.1 (13.8)	780.9 (12.9)
RSEs (FTE)	Govt+PRI	1208.5 (14.5)	2775.8 (24.5)	3297.1 (18.8)	4457.1 (19.4)
	PRI	773.9 (9.3)	1618 (14.3)	2009 (11.5)	2698.2 (11.7)
Basic R&D Expenditure ($million)	Govt+PRI	83.2	147.9	326.8	365.1
	PRI	60.9	139.1	307	318.1
Basic R&D as % of sectoral expenditure	Govt+PRI	28.5	18.4	30.5	24.9
	PRI	33.6	36.5	48.7	40.7

Note: Figure in brackets is percentage of national total

Source: National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990-2000) and Agency for Science, Technology & Research (2001 to 2008)

36. In total, A*STAR oversees 21 research institutes, centers and consortia. The initial missions of these PRIs were to develop the applied technological capabilities deemed critical to support Singapore's major industrial clusters already in existence in Singapore. In addition, some of the institutes were given the task to develop core competencies in new generic technologies (e.g. molecular and cell biology and wireless communication technologies) that are needed to attract and grow new high-tech industries that were non-existent in Singapore at the time. Despite this, and the fact that most of the PRIs had begun to shift their R&D portfolios from more downstream applied R&D to more upstream R&D, the focus on applied R&D continued into the late 1990s. As can be seen in Table 4.5, the share of expenditure on basic R&D has increased from about one-third in 1995 to almost half in 2005, before falling to 40.7% in 2009. Similarly, there was increased patenting over this period, with the average annual patents increasing ten-fold between 1995-99 (average of 3 patents issued per year) and 2000-04 (average of 32 patents issued per year), before increasing again in 2005-09 (average of 42 patents issued per year).

37. While the rapid growth of the PRIs did result in increasing public R&D spending and manpower, their changing role over time may have led to a number of problems. Firstly, arising from the new T21 initiative, the PRIs were asked to play the role of spinning off high tech start-ups as well. This new objective appears to have been hastily implemented without sufficiently working out the potential conflicts with the prior objective of licensing technologies to existing companies: some PRIs began to focus on keeping the technologies they have developed from being licensed, and instead encouraged their own R&D staff to start companies to commercialize the technologies. Secondly, there was limited cooperation between individual PRIs. While the linkages between the public R&D institutions sector and the tertiary manpower development sector were generally quite strong – most of the PRIs have been housed within the universities, and many of the principal investigators of R&D programmes at these PRIs are drawn from the academic staff of the universities – there were no incentives for PRIs to cooperate among themselves, either in research or in management functions such as technology/market intelligence gathering and intellectual property management.

38. These gaps have been addressed somewhat, first in the establishment of a number of research partnerships and research consortia to facilitate co-operation amongst research groups, e.g. the Singapore Bioimaging Consortium and the Singapore Stem Cell Consortium. Secondly a central marketing and commercialization arm was established within A*STAR. Exploit Technologies was created to identify, protect and exploit promising IP created by A*STAR's research institutes. Its responsibilities include facilitating the IP management process (i.e. the protection of inventions through patents and copyrights, etc.), analyzing the strength of resulting IP and the markets in which they can be commercialized, and working with companies to commercialize the technologies. Further, a Commercialisation of Technology Fund (COT) administered by Exploit was launched in 2003 with the aim of bridging the gap between technologies invented at the research laboratories and enterprises' needs. COT is an internal gap funding mechanism for A*STAR's research institutes to carry out technology development and refinement based on their inventions and proof-of-concept prototypes over a period of three to 12 months to translate technology disclosures to licensable IP. Companies have the option to license when technology is proven but no obligation if the project fails (Exploit website).

4.4. Intermediaries

4.5. Venture capital

39. As MNCs provided risk capital in the early years of Singapore's high tech development, there was little need to develop financial institutions to support high technology investment. Although the government has subsequently acted to strengthen the availability of financing for high-tech investment, the high-tech venture financing ecosystem in Singapore is still relatively under-developed. It was only from the 1990s that the number and amount of VC funds managed out of Singapore started to grow, spurred in part by a significant injection of co-funding by a number of government holding companies as institutional investors (Temasek Holdings, TIF Ventures) as well as the establishment of a number of VC funds directly managed by government agencies or government linked companies.

40. Despite this, the real growth of the VC industry in Singapore occurred only in 1999, with the establishment of the US$1 billion Technopreneurship Investment Fund (TIF), launched at the height of the dot.com boom under the T21 Initiative. This 'fund-of-funds' was wholly owned by EDB and aimed to jumpstart the VC industry in Singapore by inducing leading VCs to use Singapore as their regional operation hub and train a core of experienced VC professionals. Although the fund was successful in attracting several leading US VC firms to Singapore (for example Draper Fisher Jurvetson, Crimson Ventures), others that received sizable funding from the fund did not follow suit. The fund closed in the late 2000s with moderate returns.

41. The government's efforts enabled Singapore to establish itself as the preferred location for VC regional hub operations in Southeast Asia, but in terms of the volume of venture deal flows Singapore still lags considerably behind Taiwan (Wong 2006). Indeed, while the cumulative amount of funds managed in Singapore grew impressively, reaching over $16 billion in 2004, in terms of actual investment in Singapore-based ventures, the record appears to be less impressive. Over the six-year period of 2000-2005, a total of less than S$1.8 billion were invested in 500 Singapore-based firms, or just over 10% of the total VC fund managed out of Singapore in 2004. Thus a sizable portion of the VC funds managed in Singapore appears to have been invested overseas instead and their real impact on high-tech start-up formation in Singapore has been quite modest.

42. Another contributing factor to the low level of venture capital-funded deals in Singapore is the lack of availability and sophistication of business angel investing at the seed stage, which is typically needed to fund early start-ups to grow to a later stage fundable by venture capitalists. Recognizing the critical need for early-stage financing in Singapore, EDB introduced in 2001 a public co-investment scheme (Startup EnterprisE Development Scheme or SEEDS, now administered by SPRING) to stimulate early stage business angel investment. A related program, Business Angel Funds (BAF) co-funds investment by pre-approved Business Angel groups. Some of the recently introduced NRF schemes, such as ESVF, also target this gap. Both the SEEDS and BAF program was launched after consultation with the Business Angel Network (Southeast Asia) (BANSEA), an angel investment networking organization established in Singapore in 2001 by a group of Singapore-based angel investors, with network connections to investor groups in Thailand, Malaysia, Vietnam and Indonesia (BANSEA website). Similar to angel networks like the Band of Angels and Tech Coast Angels in California, BANSEA has emerged to fill the gap in early-stage start-up funding by facilitating match-making between start-up entrepreneurs and early stage investors.

Innovation infrastructures and services

43. Singapore's first science park was set up in 1980, under a government initiative seeking to emulate the success of science and high-tech clusters like Silicon Valley and Route 128. With a total land area of 30 hectares, the park was fully occupied by the mid-1990s with a mix of tenants including government agencies and numerous private companies. The development of Science Park II, with a land area of 20 hectares, began in 1993, with tenants mainly comprising ICT companies and related PRIs.

44. Following the completion of these two science park programs, the government embarked in early 2000s on a much larger infrastructure development project called One North, which would house a new innovation-based city comprising R&D facilities, campuses for new higher educational institutions, living quarters for research scientists, hotel, convention and restaurant facilities, as well and offices for venture related services such as IP law firms and VCs (Wong 2011). This was a with a view to facilitating the formation of informal networks for knowledge sharing and accelerating the growth of a critical mass of S&T expertise in Singapore (Finegold et al 2004). Occupying 190 hectares of land near to the campus of NUS, One North represents the most ambitious R&D infrastructure support project attempted by the government to-date.

45. The One North development currently comprises two major hubs. The first is the biomedical hub, known as Biopolis. Opening its first phase in 2003, Biopolis houses both A*STAR's biomedical research institutes as well as biomedical companies. The second is the hub for ICT, media and physical sciences & engineering, known as Fusionopolis and opened in 2008. As with Biopolis, Fusionopolis houses both science and engineering PRIs and corporate labs. Singapore's various industry-development public agencies (SPRING, EDB and the Media Development Authority (MDA)) are also in the process of being located there. The two hubs are located in close proximity in the hopes of facilitating opportunities for the fusion of capabilities across diverse scientific domains, thus paving the way for multi-disciplinary research.

Scientific facilities are also shared to encourage greater collaboration among the researchers. In addition, the lifestyle areas are used as test-bedding sites to accelerate the adoption of new technologies.

4.5. Linkages between innovation actors

46. Linkages between MNCs and local firms (especially those in industries supporting the MNCs) improved rapidly from the late 1980s. A number of studies (Wong 1992, 1999) indicated that the supplier-buyer relationship between the local supporting industries and their MNC buyers had contributed significantly towards inducing technological development among the former. This happened less through the unilateral efforts of the MNCs to transfer technology to their vendors and suppliers, but more through processes of indirect exposure and disclosure of technological information to suppliers. Moreover, the existence of a long-term supplier-buyer relationship helped to reduce the perceived market risks of investing in new technology by the suppliers, and thus contributed to inducing a higher propensity to invest in new technologies by the local supporting industries. Various studies (Wong 1999 and Soon 1992) indicate that the government has played an effective role in facilitating the innovation links between MNCs and their local supporting industries, through programmes like the Local Industry Upgrading Program (LIUP). For example, Wong (1999) documented how the LIUP program implemented by EDB contributed towards the rapid technological development of local precision engineering firms that supplied to the major magnetic hard disk drive MNCs. More recently, through the strategy of Industry Cluster development, EDB has facilitated the formation of joint ventures and technology strategic alliances between Singaporean firms and major foreign MNCs in a number of high-tech industries, including semiconductor wafer fabrication and chemicals (Wong 2003).

47. Inter-firm innovation linkages among local firms appear to be weak, however, and there are few reported cases of joint R&D among local firms. The kind of industry-wide R&D consortia found in Taiwan and Japan have been largely absent in Singapore. There have also been few reported cases of industry-wide collaboration in technology deployment. Overall, there appears to have been inadequate policy attention given to promoting innovation collaboration among local enterprises in Singapore, compared to Taiwan and Finland, and this appears to be a major weakness in Singapore's NIS (Wong and Singh 2008).

48. Linkages between the universities/PRIs and the enterprise sector have traditionally been relatively weak, at least until the late-1990s, due to the long gestation time needed for the PRIs to establish core capabilities relevant to industry, and the lack of focus on industrially relevant research at the universities until the late 1990s. Moreover many MNCs have looked to their headquarters and associate companies for technological needs rather than local PRIs/universities. They also preferred to tap public R&D subsidies offered for in-house R&D, so that they would own the intellectual property generated. As for local firms, most are SMEs that lack the resources and capabilities to take upstream technologies from universities to try to commercialize them (Wong, 1999). Linkages between universities and enterprises have somewhat strengthened since the early 2000s, due to increasing emphasis by the universities on commercializing technologies and on collaborative R&D with industry, particularly with MNCs. The 2005 IP and Innovation Survey found that among innovating firms who engaged in innovation collaboration, the most common local partners were HEIs and government/PRIs (52.5% and 50.8% of such firms had collaborated with HEIs and government/PRIs respectively) (Table 4.6) (Wong et al 2007, Wong et al 2006a).

Table 4.6. Innovation collaboration partners in Singapore

	Manufacturing	Services	All sectors
	% of innovating firms with innovation collaboration		
Universities or other HEIs	58.1	46.4	52.5
Government/public research institutes	51.6	50.0	50.8
Suppliers of equipment, materials, components or software	41.9	21.4	32.2
Clients or customers	22.6	32.1	27.1
Other enterprises within enterprise group	29.0	3.6	16.9
Commercial laboratories/R&D enterprises	25.8	7.1	16.9
Consultants	12.9	17.9	15.3
Competitors and other firms from same industry	9.7	3.6	6.8

Source: Wong et al 2006a.

49. Nevertheless, by tracing the backward citation of patents granted to local firms, Wong et al (2009b) found that local universities/PRIs play a relatively small role as scientific and technological knowledge sources of invention. Only 0.1% of citations from local Singapore firms were made to patents owned by local universities/PRIs. Similarly, only 2.8% of publications cited in local firms' patents were authored by researchers in local universities/PRIs.

5. Human resources

50. A distinctive feature of Singapore's NIS development is the early and sustained emphasis on building human resource competences geared to absorbing and assimilating new technologies. While the expansion of education at all levels has been a priority public expenditure focus of the government throughout the years, the relative emphasis has changed over time. In addition, the government has played critical roles in promoting industrially relevant workforce development. This has included the establishment of vocational and technical training institutes, polytechnic education and through specialized technical training programs, many of them collaborative ventures between the government and reputable overseas partners (MNCs and highly-regarded foreign industrial training institutes).

51. Overall, Singapore appears to have done well in increasing the supply of technical graduates over the years. The annual flow of graduates with S&T qualifications has increased from about 8,000 polytechnic students and 4,500 university students per year in the mid-1990s to close to 16,000 polytechnic students and 10,000 university students in 2009 (i.e. 68.4% and 52.8% of polytechnic and university graduates respectively) (see Table 5.1). The proportion of S&T graduates who hold university degrees has also increased slightly from about 35% to 39% in the same period.

Table 5.1. Graduates from S&T courses in local institutes of higher education, 1995-2009

	POLYTECHNICS				UNIVERSITIES			
	Total # of Graduates	S & T courses			Total # of Graduates	S & T courses		
		Total in S&T courses	With Advanced Diploma	% in S&T		Total in S & T courses	With Postgraduate Degree	% in S&T
1995	11,851	7,934	572	66.9	9,029	4,376	597	48.5
1996	12,759	8,755	489	68.6	9,706	4,513	709	46.5
1997	13,875	9,437	569	68.0	10,474	5,062	999	48.3
1998	15,132	10,115	594	66.8	11,496	5,636	1,190	49.0
1999	15,781	10,836	747	68.7	12,051	6,155	1,495	51.1
2000	16,371	11,046	816	67.5	13,020	6,892	2,100	52.9
2001	17,524	12,182	1,042	69.5	14,098	7,563	2,457	53.6
2002	18,306	12,785	1,217	69.8	14,901	8,189	2,814	55.0
2003	17,675	12,088	1,088	68.4	14,658	8,664	2,602	59.1
2004	19,203	13,587	914	70.8	14,944	9,372	2,833	62.7
2005	19,374	13,917	894	71.8	15,559	9,413	3,275	60.5
2006	19,107	13,753	751	72.0	15,794	9,271	2,977	58.7
2007	19,548	13,676	707	70.0	17,061	9,769	2,965	57.3
2008	21493	15158	808	70.5	17,707	9,793	3,125	55.3
2009	22,924	15,689	1,231	68.4	18,629	9,829	3,190	52.8

Data classified according to SSEC2000. S&T courses include:
- for polytechnic courses: science & related technologies; health sciences; IT and engineering sciences.
- for university courses: natural, physical & math sciences; medicine; dentistry; health sciences; IT and engineering sciences.

Data includes both full-time and part-time diploma/degree courses, as well as advanced diploma and higher degree.

Source: Wong et al (2009d); Yearbook of Statistics 2010.

52. Nevertheless, Singapore still lacks a sufficient number of highly skilled knowledge professionals, especially RSEs. Among RSEs engaged in R&D activities in Singapore, the proportion with Masters/PhD degrees remained relatively low (around 40-44 per cent during the 1990s and early 2000s, though it subsequently increased to 49.4% in 2009 (Table 5.2). The IMD World Competitiveness Yearbook (WCY) has generally rated the availability of skilled technical labor in Singapore as behind most of the advanced OECD countries, although its ranking has improved from the mid-2000s. In some ways this relative lack of RSEs is to be expected given Singapore's small size and thus limited manpower pool. However it is a major constraint to the future development of its NIS, given the critical mass of science and technology manpower needed for its high-tech industrial drive, especially in the life sciences (Wong and Singh 2008).

Table 5.2. Deepening of the knowledge base of Singapore's RSEs 1993-2009

	Percentage of Masters and Ph.D. holders among RSEs (FTE)
1993	39.3
1997	41.6
2000	43.8
2005	44.3
2006	44.8
2007	45
2008	44.2
2009	49.4

Source: National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990-2000) and Agency for Science, Technology & Research (2001 to 2009)

53. One means through which the government is trying to address this is by giving greater emphasis on the PRIs' role in training the workforce. Especially since the Third National Science and Technology Plan (2001-05), various new programmes were launched emphasising human resource development, including new scholarship schemes for postgraduate education at leading universities overseas, a scheme for postgraduate research students to undergo internships at the various local research institutes, and the funding of PRI researchers to be attached with local high-tech firms to develop their technology commercialization experience.

54. Another key aspect of Singapore's competence building policy is its policy toward attracting foreign talent. To supplement the local supply of skilled labor, the government has consistently adopted a liberal immigration policy to attract overseas skills. In 2006, foreigners comprised 30.9% of the total employment pool (Committee on Global Science and Technology Strategies and Their Effect on US National Security 2010). While precise statistics on the in-migration of qualified technical labour are unavailable, the annual R&D surveys indicate that foreigners typically accounted for almost one-fifth of the total pool of RSEs in Singapore in recent years (A*STAR, various years). Even this, however, is a gross under-estimate, as it does not include the sizeable number that had been offered permanent residence and so were not counted separately. Similarly, over one-third of Singapore's IT workforce in the late 1990s was found to consist of foreigners. The proportion is even higher in the emerging life science fields. While Malaysia was a major source of foreign talent in the early years, China and the Indian sub-continent have provided the bulk of the foreign technical professionals working in Singapore since the mid-1990s (Wong and Singh 2008).

6. SWOT analysis

55. Based on the foregoing analysis, several strengths and weaknesses of Singapore's NIS can be identified, along with future opportunities and threats. These are summarised in Table 6.1.

Table 6.1. Summary SWOT analysis

Strengths	Weaknesses
– Clean, stable government, rule of law, business friendly environment, and strong leadership with long-term strategic vision to develop STI – Well-regarded primary and secondary education system, with high English language capability coupled with knowledge of key regional languages and culture (Chinese, Indian and Malay) among the multi-ethnic population – Relatively high quality university education system with global orientation and rapidly growing international reputation in research capabilities – Sound infrastructure and policy incentive framework for rapid exploitation of new technology – Strong IP protection regime and improving supporting IP services – Openness to foreign investment and talents, meritocratic value system and multi-cultural, cosmopolitan environment conducive to attract foreign talents from diverse country origins – Strong base of foreign MNCs conducting increasingly advanced R&D activities – Strong base of advanced electronics & ICT manufacturing by foreign MNCs and offshore rig-building by local firms, creating a strong cluster of supporting engineering and services industries that meet the stringent process requirements of these advanced plants – A growing base of pharmaceutical and biomedical manufacturing and water technology companies – Strong business and cultural links to the two giant emerging markets in Asia – China and India	– Insufficient Scientific & technical manpower – Relatively late investment in advanced R&D; cumulative stock of cutting-edge, patented technologies for commercialization remain lower than most of the advanced small European economies and Taiwan and Korea – Small base of indigenous high tech firms compared with economies like Taiwan and Korea – Small domestic market and lack of critical mass of advanced lead-user firms willing to adopt unproven innovation by young start-ups – Relatively poor linkages within private sector and between private sector and universities/ PRIs, and relatively under-developed technology commercialization system – Social cultural norm & high opportunity cost of foregoing career in government and large private enterprises that discourages entrepreneurial pursuits among the highly educated; relative lack of successful local high tech entrepreneurs who can serve as role models – Broadband ICT infrastructure deployment has been slower than in leading regional competitors such as Hong Kong and Korea – Fragmentation of Southeast Asian markets reducing the ability of local high tech firms to grow by scaling to the regional markets
Opportunities	**Threats**
– Windows of opportunities for Singapore to develop and strengthen her regional innovative hub role in emerging technologies like IDM, clean tech, water tech and biomedical technologies through continuing public funding support and strategic cluster development policies to attract foreign R&D investment and S&T and entrepreneurial talents into these sectors – World-class, globally-oriented universities with strong public funding are in position to attract top talents from overseas and to develop collaborative R&D and educational links with leading universities in the world through programs like CREATE – Rapidly growing volume of cutting edge technology from IHLs and PRIs will lead to greater supply of technologies for commercialization by Singapore-based firms and entrepreneurs – Potential to leverage her close geographic proximity and strong cultural links to major, fast growing regional emerging markets (China, India, ASEAN) to tap their increasing market demand for innovative products & services adapted to their cultural tastes and needs – Potential role for Singapore to become a leading regional education & training, venture financing, IP services hub for innovative & entrepreneurial activities in Asia	– Cost pressures due to growing competition from other emerging markets, especially China, India and ASEAN neighbors – Vulnerability to volatility in the global economy, given Singapore's openness – Increasing competition from China and India in developing competing hubs in the same key high tech sectors such as biomedical technologies, interactive digital media and clean/environmental technologies targeted by Singapore – Continuing fragmentation of Southeast Asian markets, coupled with protectionist tendencies by some regional economies (e.g. Malaysia, Indonesia), that hamper pan-Southeast Asian market integration and Singapore's regional innovation hub role in Southeast Asia – High dependence on foreign S&T professionals, many of whom may not be fully rooted in Singapore and may be lured back to their home economies as these become more attractive over time – Growing income inequality and potential political backlash against continuing opening up of economy to foreign talents

56. While Singapore’s NIS is certainly the most advanced in Southeast Asia and hence has the opportunity to further consolidate its role as the region’s innovation hub, while leveraging on its geographic proximity and strong business and cultural links to the two major emerging markets in Asia – China and India – the same geo-positioning also implies potential threats. As a small economy the key challenge is for Singapore to be able to move nimbly and strategically to stay ahead of the regional competitors in capability development in selected S&T technology clusters. Its continuing ability to attract global talents, especially innovative and entrepreneurial talents, is key to achieving this, even as it seeks to nurture greater entrepreneurship and innovation among its local population.

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