PUTTING SINGAPORE ON THE GLOBAL INNOVATION MAP

The shifting role of the state in the rapidly changing environment

Lai Si Tsui-Auch, Sherwin Ignatius Chia and Anica Liu

Introduction

Globalization presents both advantages and disadvantages to the role of state in managing a knowledge-based economy through innovation and technological development. Although globalization has allowed collaborations to take place more easily through technological improvements, nations seeking to sustain the growth of their economies have to face intensive competition – both regionally and globally – in terms of the cost of doing business as well as attracting and retaining both foreign investments and talents.

In this chapter, we focus on the role of the developmental state in developing technologies and pursuing innovation in the context of global and regional competition. We choose Singapore as a case for three reasons. First, Singapore is a unique nation in which there are no natural resources and no hinterland to support a domestic market, but yet is located in a thriving Asian region that constitutes a growing market, and attracts and provides both investments and human resources. Next, it is a well-known city-state in its attempt to catch up with high-technology development. Last, it has been an exemplar of the state-led development strategy in directing technological and industrial upgrading for late-industrializing nations in the past four decades. Unlike South Korea which has adopted a ‘go big’ strategy (by relying on chaebol for innovations) and Taiwan which has chosen a ‘go small’ strategy (by harnessing small and medium-sized enterprises for entrepreneurial undertakings), Singapore has been persistent with its ‘go global’ strategy, through attracting FDI and importing foreign talents (Wong 2011).

This chapter is aimed to present the trajectory of technological development since the 1970s and to analyse how it has been shaped by the developmental state amid global and regional competition and how it has in turn changed the role of the state. We review and update the state’s past success in developing the electronics industry and information technology, its subsequent bet on biotechnology and its most recent new pickings in clean technology. Drawing on the typologies of R&D (Amsden and Tschang 2003), we contend that the evolution from production-related R&D to applied research has generally taken place due to
policies of the developmental state and an adaptation of the Triple-Helix nexus (Etzkowitz et al. 2000) in a small open economy (Wong 2007). However, the attempted shift from a manufacturing economy to a knowledge-based economy has been fraught with critical challenges.

Based on an analysis of the development of these key industries, we discuss two issues: (1) In what ways has the state enabled or inhibited industrialization and technological development in the context of regional competition for foreign talents and markets? (2) Has there been a retreat of the developmental state amid profound uncertainties in developing science-based industrialization?

The Singapore context

After independence in 1965, the government assumed the role of a developmental state alongside its counterparts in Taiwan, South Korea, Japan and Malaysia (Woo-Cummings 1999). To speed up economic modernization and to deal with unemployment at the time of independence, the state established government-linked corporations (in which the government takes equity) and enticed multinational corporations (MNCs) to invest in the country. As Singapore has a smaller domestic market than Hong Kong and Taiwan and has no hinterland since its separation from the Malayan Federation in 1965, it has attempted to overcome its natural weakness by offering an entry to the Southeast Asian market through creating an international business and language (English) environment, efficient telecommunication and transportation systems, as well as business-friendly government policies.

After two decades of independence, Singapore shifted from being a developing country to joining the league of Asian newly industrialized countries. As a very small country lacking a ‘natural’ hinterland for cheap labour and land supply, Singapore had fewer alternatives other than shifting from IT/electronics manufacturing towards knowledge-intensive industries since the mid 1980s, being increasingly integrated into the global system of knowledge production and exchange (Phillips and Yeung 2003; Wong 2007; Wong 2011).

However, unlike Japan and South Korea in which the development of knowledge-intensive industries stem from the private sector, Singapore’s private sector, which faces financial constraints, has been weak in technological upgrading and knowledge-intensive industries. Unlike the bank-centred financial system of Germany in which firms rely on banks to finance investments (Casper 2000), Singapore’s banks have not offered patient finance. Moreover, the country has not established a vibrant venture capital industry. Unlike the US venture capitalists who are willing to accept high technological uncertainty and short- to medium-term financial losses in return for the prospect of very large gains in the future, most of the venture capitalists in Singapore/Asia have been risk-adverse.

Other than the constraints in finance, the development of knowledge-intensive industries has been hampered by a lack of qualified scientists. The government fostered education in engineering, business, finance and banking rather than natural science. Whereas Taiwan has been able to attract its US-educated professionals who have competed in Silicon Valley to return home to set up their own businesses, Singapore has continued to suffer from brain drain, and has few alternatives but to adopt liberal immigration laws to foster the recruitment of foreigners.

Despite the structural constraints, Singapore does have geographical, political and institutional ‘advantages’ over other countries in undertaking science-based industrialization such as the biomedical industry. Geographically, its unique geographic location (on the sunbelt), which provides Singapore with radiation of 50 per cent more than that in Germany and Japan (the other two major hubs for solar technology located at temperate regions), enhances its opportunity to develop ‘clean technology’ (Ng 2010).
Politically, given the dominance of a ruling party without credible opposition parties (Worthington 2003; Gourevitch and Shinn 2005) and the absence of protests and non-governmental organizations that lobby against genetic engineering, the Singapore government and research institutes have been largely free from ethical and political debates on biotechnology development.

Institutionally, the state evolved a capability through identifying a nodal agency, the EDB, to spearhead industrial and economic development (Tsui-Auch 2004). Being established as a statutory board in 1968, it has enjoyed a clear political mandate for its mission and has been endowed with the power to coordinate and command other state agencies to accomplish tasks. As a nodal agency with financial and decision-making power, the EDB can offer financial incentives and physical facilities to MNCs and secure their entry into Singapore. It could seek cooperation from the Jurong Town Corporation to establish industrial infrastructures; the Development Bank of Singapore for financing; the state-led National Trades Union Congress to restrain labour unions and the tripartite National Wage Council to regulate wages and to upgrade labour skills (Lim 1987); the Ministry of Education to boost the promotion of science education; the Ministry of Science and Technology to spearhead scientific research; the National Science and Technology Board and its successor, the Agency for Science, Technology and Research (A*STAR), to manage research across universities and public research institutes and steer research towards ‘world class’ standards. Internationally competitive compensation packages have been offered to lure star scientists to Singapore.

**Singapore’s path to participation in the innovative world**

*Joining the electronics/IT industrial development race*

The electronics segment, which has remained one of the main pillars of economic growth, began in the late 1960s, whereas the IT segment started in the 1980s. FDI in the electronics segment contributed greatly to the economic growth in Singapore especially during the initial years. The initially functional role of IT in the civil service has led to the important economic role of IT as a service provider. It has also led to the service sector playing an increasingly important role in Singapore’s economy. Overall, state intervention has generally been successful in these two industries.

**Electronics segment**

The electronics segment has a backwards linear trajectory of R&D based on Amsden and Tschang’s (2003) categorization of R&D, starting with advanced development and moving towards applied research. Its development can be divided into three main periods so far.

*1960s to 1979: from survival to growth*

Given Singapore’s situation, a focus on labour-intensive manufacturing was the most attractive option to reduce unemployment and increase economic growth in the early 1960s (Lim and Pang 1981). The EDB’s heavy promotion of Singapore as a low cost manufacturing base (Chan 2002), coupled with generous tax incentives (Lim 1987), attracted substantial investments from large foreign MNCs (Lim and Pang 1981). Over time, the state pushed for more diversification, by pursuing the manufacturing of consumer and industrial electronics. By the mid 1970s, component manufacturing and consumer electronics manufacturing were the two largest
subdivisions (Lim and Pang 1981). A recession struck in the mid 1970s and employers were forced by the state to retrench foreign labour (Lim 1987). This increased labour costs and labour shortage made Singapore less attractive for labour-intensive manufacturing (Lim 1987; Chalmers 1991; Chua 2012). Subsequently, it triggered a shift from a development paradigm anchoring on lower value-added production by cheap labour to one emphasizing techno-industrial innovation by academic labour force. Thus in 1979, the state advocated skills upgrading and created incentives to attract investments towards higher value-added and skill-intensive production such as integrated circuits designs and wafer fabrication (Lim 1987; Chalmers 1991). The JTC announced the building of a new science park to encourage more R&D between academia and industry (Phillips and Yeung 2003). The NWC allowed suppressed wages to increase towards market rates (Lim 1987).

1980s to 1989: promotion of R&D

In the 1980s, the state merged and established universities to produce engineering talents. The EDB provided additional incentives for MNCs to use Singapore as their regional headquarters leading to foreign MNCs expansion towards the late 1980s (Chalmers 1991).

Subsidiaries of MNCs in Singapore began to engage in R&D activities, but primarily in advanced and exploratory development such as product design and fabrication (Mathews 1999). Electronic goods manufacturing began to diversify towards computer printed circuit board assemblies and hard disk drive manufacturing (A*STAR 2012a). However, cutting edge R&D activities were still lacking in local firms and subsidiaries of MNCs.

1990 to present: innovation and knowledge-led growth

The EDB re-emphasized its commitment by aiming ‘to develop Singapore into a world-class electronics manufacturing hub with end-to-end R&D capabilities’ (EDB 2011: 1). Several public research institutes engaging in applied research were established in the early 1990s (A*STAR 2012a). However, R&D activities were confined to advanced and exploratory development, with the exception of the storage industry moving towards applied and basic research.

However, the electronics segment was hit badly first by the global health crisis inflicted by SARS in 2003 and then by the recent global economic crisis with a significant drop in output and increase in unemployment rates (Jordan 2009). The NWC announced wage reduction to cope with the SARS outbreak (Lim 2013), and the state introduced several measures to preserve jobs during the recession (Jordan 2009).

IT segment

The IT segment followed the similar R&D trajectory of the electronics segment. However, the state’s intervention through deliberate planning was more obvious in this segment. Its development can be classified into two periods.

1960s to late 1990s: the birth of IT

In the 1960s, IT referred to telephone services, and the telecommunications company was state-owned. However, efforts were made to use IT as one of the key technologies in enabling economic growth by the late 1970s (Chua 2012). When the state’s information and communication technology master plan was launched, research institutes were established in
collaboration with foreign MNCs initially to train IT talents but subsequently to engage in applied research. For example, IBM was engaged to assist National University of Singapore to establish the Institute of Systems Science in 1981. The Information Communication Institute of Singapore was established in collaboration with AT&T Bell labs in 1989 (Wong 1992; Wong 1996; A*STAR 2012a).

Late 1990s to present: IT as an economic pillar

This period saw the civil service’s reduction of front desk manpower through online platforms and the provision of IT services (i.e. e-business and business productivity consultancy services) as a potential economic growth sector (iDA 2000; Chua 2012). In addition, the late 1990s saw the gradual liberalization of the telecommunications industry with the state-owned telecommunications provider becoming privatized to form SingTel (Chua 2012). Although full liberalization of the telecommunications industry took place in 2000, strict regulations inhibited initial competition growth (Chua 2012). Temasek Holdings’s (the largest government-linked holding in Singapore – SingTel’s parent company) acquisitions of stakes in telecommunications companies across Asia and Australia generated hostility from host country governments and nationals and, specifically in Thailand, provoked a deep political crisis that subsequently led to Temasek’s high financial loss (Lau 2001).

RESULTS

Obviously, in both the electronics and IT segments, the state played a crucial role in attracting R&D investments and developing R&D capabilities (starting with exploratory development) through the control and coordination of various agencies and utilization of the Triple-Helix nexus (Etzkowitz et al. 2000).

For a small open economy, the results have been remarkable. The electronics segment contributed almost a third of the manufacturing output in 2011. The IT segment drew revenue of S$70.39 billion in 2010, of which 66 per cent was contributed outside of Singapore (iDA 2011). FDI abroad has also been increasing with manufacturing and info-communications contributing 24 per cent and 5.1 per cent respectively.

In particular, there has been a state-led change towards a modern research and science-based economy employing university trained personnel for higher value added process. Researchers grew almost nine-fold while R&D expenditure rose almost twelve-fold between 1982 and 1992. R&D expenditure in the engineering and technology research areas, which are related to the electronics and IT industry, accounts for 62.8 per cent of total R&D expenditure in 2011 (see Table 13.1). However, the majority of the expenditure was devoted to exploratory development and was mostly contributed by foreign companies.

There are two main challenges facing the electronics and IT industry. The first challenge is to strengthen local firms and public institutions, and grow their R&D capabilities across all categories of R&D. Local firms and public institutions contributed less than a quarter of R&D expenditure in engineering and technology research areas, which are related to the electronics and IT industry, accounts for 62.8 per cent of total R&D expenditure in 2011 (see Table 13.1). However, the majority of the expenditure was devoted to exploratory development and was mostly contributed by foreign companies.

The second challenge is to navigate through political sensitivities while acquiring foreign assets that are strategic to their national economies. This is illustrated in the outward foreign investments by government-linked SingTel and its parent company, Temasek Holdings, which have generated hostility in host economies for their telecommunications investments abroad.
Towards a science-based industrialization: participating in the biotech revolution

The developmental state of Singapore surely did not want to miss the ‘biotech revolution’. As with its counterparts in South Korea and Taiwan, it has envisioned its economy as a biotech hub, being a gateway into the growing China market. Singapore’s biotechnology development, however, has diverged from that for the electronics and IT industry which followed the typical approach of late-industrializing economies that progresses from production and development-type research to product design. To foster biomedical development since the late 1980s, the state has established the whole value chain, embracing not only the ‘D’ part (exploratory development and advanced development) of the ‘R&D’ but also the ‘R’ part, fostering basic research and applied research. Its development can be classified into three periods.

1988 to 1997: a broad-based approach

In this initial period, a broad-based approach towards biomedical development was adopted. Other than high value-added pharmaceuticals and diagnostics, the EDB aimed to foster agricultural and food biotechnology to meet the needs of local small- and medium-sized enterprises in the food sector.

The EDB offered financial incentives to attract MNCs to establish R&D processes in the country, and enticed those that had already established manufacturing facilities in the country to invest in R&D. To aid the commercialization of inventions, it set up a venture capital fund to make direct equity investments in viable biomedical projects both locally and abroad. The JTC developed four science parks to foster exchanges between industry, academia and the government. The NSTB was tasked to oversee public research, and started to fund the establishment...

Table 13.1 R&D expenditure in Singaporea,b

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<td>GDP (Current prices) ($mil)c</td>
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<td>134207.6</td>
<td>157136.1</td>
<td>231580.6</td>
<td>326832.4</td>
</tr>
<tr>
<td>Current prices ($mil)</td>
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<td>1792.14</td>
<td>3232.68</td>
<td>5009.70</td>
<td>7448.48</td>
</tr>
<tr>
<td>per cent of GDP</td>
<td>1.13</td>
<td>1.34</td>
<td>2.06</td>
<td>2.16</td>
<td>2.28</td>
</tr>
<tr>
<td>per cent of GDP by public sector</td>
<td>0.44</td>
<td>0.37</td>
<td>0.39</td>
<td>0.74</td>
<td>0.86</td>
</tr>
<tr>
<td>per cent of GDP by private sector</td>
<td>0.68</td>
<td>0.44</td>
<td>0.71</td>
<td>1.42</td>
<td>1.42</td>
</tr>
<tr>
<td>per cent of GDP by local firms</td>
<td>N.A.</td>
<td>42.96</td>
<td>42.39</td>
<td>31.85</td>
<td>24.28</td>
</tr>
<tr>
<td>per cent of GDP by foreign firms</td>
<td>N.A.</td>
<td>57.04</td>
<td>57.61</td>
<td>68.15</td>
<td>75.72</td>
</tr>
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Notes: All sources are taken from the respective year of A*STAR’s national survey of R&D in Singapore unless indicated otherwise.

a Industry was used instead of research area in 1992 and 1996.
b Research area classification was changed in 2006 and Energy was added in 2011.
c Sources from World Bank.
of three large research institutes, covering various steps of the value chain of the biopharmaceutical industry.

1997 to 2006: refocusing and resource orchestration

The Asian financial crisis of 1997 devastated the property sector and banks in Singapore. The political turmoil in Indonesia rendered Singapore’s grand scheme of regional division of labour in manufacturing risky. Expecting the relatively unscathed China to become an industrial and technological powerhouse, the Singapore government felt the urgent need to develop knowledge-based industries to maintain its competitiveness.

In early 1999, the EDB launched an economic blueprint that aims to develop Singapore into a vibrant and robust global hub of knowledge-driven industries. It identified biomedical industry (including pharmaceuticals, medical devices, health care and biotechnology) as one of the four pillars of the economy. The shift from a broad-based approach, which includes agro-biotechnology to an approach that focuses on human health-related life science (particularly on cancer research), represents an attempt to define a niche and to pool resources to yield results in a shorter time span.

A new focus was to nurture domestic start-ups, which deviated from the conventional approach to attract FDI only. The EDB has adopted the resource orchestration approach, designing policies to provide start-ups with seed funding, access to incubation space in a new science park (the Biopolis), technical advice, business consultancy, and networking opportunities.

To support the new focus, the EDB set up an International Advisory Committee that included representatives from MNCs. With respect to the state sector, the A*STAR invested in three new research institutes and merged two existing institutes to build a biomedical science base. Scientists in the existing institutes were strategically directed to strengthen biomedical sciences. The educational institutions from primary schools to universities were mobilized to nurture future technopreneurs and qualified scientists. To build an academic labour force, life science has been incorporated into every subject taught from Primary 1 to pre-university. To entice young students to study biomedical sciences, the government has offered scholarships to recipients studying biochemistry, biophysics and developmental biology.

2007 to present: changing state approach to organize science-based industrialization

Despite the state’s highly coordinated efforts for two decades, value-added investment in terms of R&D and value-added gains have been limited. Some industry stakeholders started to complain about the slow pace of commercial growth and questioned whether the investment in biomedical science was worth undertaking, whereas others criticized the state strategy for being too ambitious (Wong 2011). Although the state has attempted to promote ‘stars’ – star start-ups, star scientists and world class partnerships – to portray success in the biomedical science, the acrimonious dissolution of the A*STAR and Johns Hopkins University partnership in 2006 came as a severe setback to its foreign talent-dependent industrialization strategy.

The state’s management of biomedical science development began to change in 2007. The extraordinary technological and market uncertainties have rendered the developmental state’s past practices of picking winners impractical. While its financial commitment to nurture biomedical industry has continued to increase, the proportion allocated to biomedical science and disbursement of public funding indicated a change in its management of science and technology development. For example, while S$332 million, i.e. over half of all R&D funds to public research institutes, was allocated to biomedical research in 2005, that for this research
stream dropped to S$263 million in 2006, amounting to about 42 per cent of all funds allocated to public research institutes and the proportion has remained as of 2011 (A*STAR 2006, 2007, 2012b). Moreover, instead of centralizing power in the EDB and A*STAR for allocating funds in a coordinated fashion, the government has created new funding streams. This suggests that the sector’s technological and market uncertainties have rendered a decentralization of expertise, which has subsequently led a more horizontal distribution of authority in shaping science-based industrialization (Wong 2011).

RESULTS

The state’s approach to build up its biomedical science base is consistent with its proven strategy of harnessing Singapore’s location advantages in the attraction of MNCs to strengthen its domestic technological capacity and to foster the growth of local supporting industries. MNCs accounted for 79 per cent of the private sector R&D spending, and employed 69 per cent of researchers in the biomedical industry (A*STAR 2012c). So far, nearly all the large pharmaceutical companies have operations in Singapore, including twenty-eight biopharmaceutical plants as of January 2013. However, most companies made investments in manufacturing rather than those in R&D, despite the government’s hopes for the opposite. As with the case for electronics manufacturing and IT industry, the entry of MNCs has triggered the growth of SMEs as suppliers of materials and research services for MNCs rather than as innovators in the biomedical industry.

The development of the biomedical industry has enabled the state to diversify its manufacturing base; biomedical output surpassed that of electronics, accounting for 25.5 per cent of last year’s manufacturing output (Chia 2013). However, growth in commercial biomedical output has increasingly concentrated in lower value-added manufacturing, contrary to the expectation of the state. Value-added constituted nearly 75 per cent of the value of total biomedical manufacturing output in 1999; its share was, however, only 46 per cent in 2010 (EDB 2012a).

With respect to public research, the public research institutes have shown significant achievements. Scientists have published several papers in prestigious international refereed journals. However, the research institutes have encountered difficulty in attracting and retaining foreign scientists as scientists have to cope with constantly changing missions, goalposts and foci, as well as a lack of transparency in organizational change management (Tsui-Auch 2004). The constant promotion of technopreneurship, rosy job prospects and scholarships might lure Singaporean students to study biomedical science. Yet it remains to be seen whether the pragmatic students can be persuaded to pursue scientific discovery.

Diversifying the science-based industrialization: creating an Asian clean technology hub

Given the tremendous market and technological uncertainties in science-based industrialization, the Singapore government has worked to diversify into technologies other than biotech. Essentially, its ‘hub development strategy’ applies not only to the biomedical science but also to clean technology. Nowadays an environmentally sustainable economic development and the need for alternative clean and renewable energy have become urgent for nations worldwide as a result of global climate change, urbanization and the depletion of fossil fuels (Jung et al. 2000; Kannan et al. 2007). In this context, Singapore, a highly urbanized country that lacks natural resources, has identified the clean technology industry as a new strategic economic growth area, with clean energy (such as solar energy and biomass) as an important sector since the mid 2000s.
The ultimate aim is to turn Singapore into Asia’s carbon hub and global hub where clean energy solutions are developed, tested and imported overseas.

The nation has several advantages to support its clean technology development. First, the nation’s industrial infrastructures have provided a firm base for this new industry, including the existing strengths in electronics, precision engineering and chemicals industries for the manufacturing of solar wafers, cells and modules (EDB 2012b). Second, Singapore has the potential to become an Asia-Pacific carbon hub given its strategic connectivity to carbon markets, as the Southeast Asian region is one of the biggest sources of carbon credits after China and India with nearly 29 per cent of the global net carbon release from deforestation as well as the strength in providing financial and legal services (Phat et al. 2004; Hextall 2009; Cho 2011). Being embedded in the Asian region, Singapore can take advantage of its strategic location to provide culturally and socially acceptable technologies to its neighbouring countries.

2007 to present: the birth of clean technology industry

Singapore has been promoting clean technology industry from three aspects since 2007: creating an institutional environment, providing financial incentives and supporting higher education institutions. First of all, several agencies have been set up to support the new focus. The Energy Innovation Programme Office (EIPO), which was established in 2007, is a key inter-agency workgroup to implement and coordinate the various research programmes, and to leverage on the strengths of different government agencies for a comprehensive approach to developing clean technology (NRF 2007). In 2007, government’s initial funding on the clean technology industry amounted to S$35 million, amounting to 5.5 per cent of the total R&D expenditure, with the blueprints being composed of five key pillars: innovative research and development, developing manpower, grooming Singapore-based enterprises, branding the industry internationally and growing a vibrant industry ecosystem. In 2011, the EIPO announced the allocation of an additional S$195 million to promote R&D in the energy sector in the five-year period to 2015 (EDB 2011). Moreover, in 2009, the Monetary Authority of Singapore issued a circular providing details of the Enhanced Tier Fund Tax Incentive Scheme, which included emission derivatives while previously it was limited to tangible commodities such as oil, metals and agro-commodities (PWC 2009; Sethuraman 2009). In 2012 the JTC established the construction of CleanTech park, which serves the function of fostering a conducive environment for collaboration between industry and academia (JTC 2012). Moreover, the government also supports higher education institutions, including the establishment of research institutes such as the Energy Research Institute and the Solar Energy Research Institute of Singapore.

Currently, researchers across disciplines are targeting different aspects of R&D, from advanced development to applied science and even to pure science. The government actively positions the nation as a ‘living laboratory’ for companies to test and commercialize innovative energy solutions that are customized for the urban tropics (Goh 2012). By 2015, the clean technology industry is expected to meet the targets of creating S$3.4 billion value-add to the GDP and 18,000 jobs across a broad range within the industry (EDB 2012b).

RESULTS

The outcomes of the development of clean technology are encouraging so far. It has attracted a significant number of foreign and local SMEs and MNCs that are leading companies in various sub-fields in clean technology. Many of them have selected Singapore as the regional...
headquarters or hub (EDB 2012b). Some leading MNCs have set up collaborative projects with local academic institutes. However, challenges and uncertainties still exist in this new field. For example, Vestas, one of the giants in wind industry, which celebrated in 2008 the opening of an Asian R&D centre in Singapore with a plan to invest up to S$500 million in Singapore to advance research in wind power, closed the centre and laid its employees off in 2012 (Vestas 2008; Dvorak 2012).

**A state-led innovation system: achievements and challenges**

Notably, the nation has evolved the R&D capability from scratch towards applied research for electronics, IT, clean technology and biomedical industries. The global competitiveness report by the World Economic Forum provided some evidence of this success: Singapore has steadily increased its global competitiveness ranking from fifth in 2008 to second in 2012. The state has also been partially successful in creating an ecosystem of R&D, which is indicated by data presented in Tables 13.1 and 13.2. Total portion of R&D expenditure per GDP has been increasing from 1.13 per cent in 1992 to 2.28 per cent in 2011. While public R&D expenditure increased about twofold from 0.37 per cent in 1996 to 0.86 per cent in 2011, private R&D expenditure increased threefold from 0.44 per cent to 1.42 per cent. However, foreign firms still account for 75.7 per cent of the private R&D expenditure and constituted the majority in all categories of R&D in 2011.

The national innovation system helped to increase the level of skilled expertise for the industries. The triple helix model is also starting to show some success. Public research institutes have been engaging in collaborations with the academy and the industry (A*STAR 2012a). The total researchers, scientists and engineers (RSE) grew from 15,366 in 2001 to 29,482 in 2011 (with Singapore citizens and permanent residents RSE decreasing from 79 per cent in 2001 to 73.6 per cent in 2011). Exploratory R&D, which is the major category of R&D, accounted for over 45 per cent of the total R&D expenditure throughout the last two decades. Total patents awarded increased from twenty in 1992 to 855 in 2011. Sales revenue from commercialized products showed that foreign firms contributed over 75 per cent over the past two decades, whereas the local firms yielded below 25 per cent. Licensing revenue from patents showed that local firms contributed 29.2 per cent in 2006 but this increased to 51.4 per cent in 2011. Although local firms show improvements in terms of licensing revenue, the sales revenue is dominated by foreign firms. This suggests that local firms have difficulties in translating their patents into commercial success.

*Table 13.2 R&D output in Singapore*

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<tr>
<td>Patents awarded</td>
<td>20</td>
<td>91</td>
<td>461</td>
<td>933</td>
<td>855</td>
</tr>
<tr>
<td>Sales revenue from patents (S$mil)</td>
<td>N.A.</td>
<td>88360.66</td>
<td>16638.00</td>
<td>25672.53</td>
<td>13466.72</td>
</tr>
<tr>
<td>per cent by local</td>
<td>N.A.</td>
<td>24.96</td>
<td>15.34</td>
<td>21.55</td>
<td>24.58</td>
</tr>
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<td>per cent by foreign</td>
<td>N.A.</td>
<td>75.04</td>
<td>84.66</td>
<td>78.45</td>
<td>75.42</td>
</tr>
<tr>
<td>Licensing revenue from patents (S$mil)</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>137.41</td>
<td>92.78</td>
</tr>
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<td>per cent by local</td>
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<td>N.A.</td>
<td>N.A.</td>
<td>29.19</td>
<td>51.36</td>
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<td>per cent by foreign</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>70.81</td>
<td>48.64</td>
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Note: All sources are taken from the respective year of A*STAR’s national survey of R&D in Singapore unless indicated otherwise.
In summary, the technological development in Singapore has gained critical acclaim. The country has established a comparatively strong R&D establishment in fewer than two decades, established collaborations with renowned research institutes and industrial players, recruited prominent scientists from all over the world and built an academic labour force constituted by Chinese, Indians and Malaysians other than the locals. It has also attracted substantial FDI and sustained some local start-ups and large firms (see Table 13.3). The state has no doubt achieved considerable short term success in applied, advanced and particularly in exploratory research. However, its innovation system, for example, in biomedical science, is hampered by constant changes in policy and goalposts, difficulty in attracting and retaining scientists, the dominance of MNCs that focus on manufacturing or downstream R&D and few home grown start-ups. The Singapore government has long realized that it is necessary to develop local firms in the event that ‘footloose’ (Caves 2007) foreign MNCs relocate their operations. Several local MNCs are created, although most are government-linked. Yet when they expanded beyond Singapore by making overseas acquisitions, they tended to arouse hostility among foreign nationals and governments, particularly for the telecommunications industry. In addition, Singapore companies have yet to be in the fifty most innovative companies as indicated in the report by Fast Company, whereas local firms from China (TenCent in 2012, Huawei in 2011, Alibaba in 2010), Korea (Samsung in 2010 and 2011) and Taiwan (HTC in 2010) have been making headlines as global

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<th>Electronics</th>
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<th>Clean Technology</th>
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<tbody>
<tr>
<td>Foreign</td>
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<td>IBM</td>
<td>Abbott</td>
<td>Renewable Energy Corporation</td>
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<td>Globalfoundries</td>
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<td>Tata Consultancy Services</td>
<td>Lonza</td>
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<td>Mediatek</td>
<td>Merck Sharp &amp; Dohme</td>
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<td>3M</td>
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<td>and Startups</td>
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<td>Lynk Biotechnologies</td>
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<td>Singapore</td>
<td>Engineering Venture</td>
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Note: Local startups are in italics.

Sources: EDB factsheets, company websites and media reports.
innovation leaders. This is surprising because in the innovation and sophistication sub index of the global competitiveness report, Singapore has been maintaining its ranking while China’s, Korea’s and Taiwan’s rankings have been declining. This could suggest other factors that might have inhibited Singapore from producing innovative companies in technology.

We argue that a strong, activist state with a centralized approach to managing technological and economic development can be a double-edged sword, enabling the prompt development of the manufacturing economy up to the 1980s, but inhibiting science-based industrialization, local innovations and overseas expansion of its own government-linked corporations in the recent decades.

The shifting role of the state in a rapidly changing environment

While a top-down, centralized approach of state management of technological and industrial development has fostered prompt decision making, it has rendered bureaucratic action insensitive to the changing environment. Essentially, the state has locked into its past success with developing foreign-capital dependent, labour-intensive industries. Lock-in can be advantageous when the environment remains more or less the same. However, it can have negative consequences in case of radical changes in the environment.

The ‘lock-in’ has prompted the bureaucrats to maintain a low-risk investment strategy that defeats its claim to nurture local start-ups. Driven by risk avoidance, the EDB and its other agencies adopted some strategies that are unfavourable to nurturing a science-based industrialization. First, unlike its Korean and Taiwanese counterparts which were tasked to develop local capacity, the EDB favoured foreign companies over local start-ups. Hence, most domestic companies tend to tie up with MNCs and lose their small firm dynamic. Second, it favoured government-linked spin-offs over privately funded start-ups, reflecting the mentality to ‘make’ winners. Next, it tended to fund projects in the lower-risk market segments rather than the higher risk segments. Last, with an imperative to ensure performance and yield quick returns, the government agencies tended to subject research institutes to great pressure to prompt commercialization and imposed constant organizational change as seen in the development of biomedical science. However, science-based industrialization depends more on public science than many other technologies (McMillan et al. 2000). Scientists who lose trust in the establishments often seek positions elsewhere. When their exit is not well managed, the reputation of the institutes is often eroded, rendering it difficult for them to recruit scientists in the future.

Notably, the strong state management also inhibits overseas expansion of the government-linked enterprises. Although the government-linked corporations could gain financial and policy support from the state for their overseas expansion, it was hindered by the government-linked label. For instance, SingTel’s failure to acquire Cable & Wireless of Hong Kong Telecom was attributed mainly to China’s reluctance to allow a Singaporean entity to control its telecommunications assets (see Jayasankaran 2001; Mauzy and Milne 2002), given the ownership and control links between SingTel, the government and the political (Lee) family in Singapore (Yeung 2004). In another case, Temasek Holdings’s acquisition of a controlling stake in Thailand’s Shin Corp., which was owned by the family of the nation’s then Prime Minister Thaksin Shinawatra, triggered a deep political crisis that subsequently led to a military coup in 2006. That Thailand’s strategic industry was sold to a company that was wholly owned by a foreign government intensified the opposition. The political consequences that unfolded after the coup resulted in numerous stumbling blocks for Temasek’s investments in Thailand. The Shin’s share price fell drastically, reportedly leading to paper losses for Temasek of over S$800m
as of November 2006 (Arnold 2006). These two incidents show that government-linked corporations were at times impeded by their ownership structure and the relative lack of political experience in operating in foreign countries. The Singapore political culture moulded by the one-party state without credible opposition parties (Worthington 2003; Gourevitch and Shinn 2005) might sustain the political insensitivities that government-linked corporations portray towards political resistance in the host economies.

Given the increasing complexity in regional and global economic competitions in technological and industrial development and increasing nationalism in neighbouring countries, the Singapore state has had to rethink its role in the economy. As stated above, the states of the newly industrialized economies compete to develop themselves into regional hubs or springboards into the Chinese market, and have been willing to invest heavily in this race. Nevertheless, the development of science-based industrialization is very different from that of electronics and the IT industry. For the electronics/IT industry, the development of electronics manufacturing paved the way for that of IT industries, and the market for such products and services were rather certain and quick financial returns can be generated. Both the biomedical industry and the clean technology industry, however, have been fraught with great uncertainties in market, product development and regulatory environments. Moreover, the Singapore government officials have to catch up with new development in academic knowledge in these fields. Together with the factors including weak science tradition and small domestic market, the Singapore state, as with its South Korean and Taiwanese counterpart, has gradually made a ‘strategic retreat’ of the developmental state (Wong 2011: 13). Whereas it has continued to invest heavily in biomedical industry, it has diversified its bet into new areas such as clean technology and has retreated from picking and creating winners. In addition, it has scaled back its ambition to venture into basic research in a wide range of fields, and has become more realistic in focusing on the niche of cancer research. This refocusing on profitable innovations rather than basic research is also shown in the development of clean technology. By so doing, its approach resembles the niche approach that has been adopted by its Taiwanese counterpart, and continues to deviate from South Korea’s long-standing approach to developing a broad base covering both upstream, basic research and downstream, industry focused development. However, whereas the Taiwanese state thrives on its ‘go local’ strategy, depending on the thriving SMEs to capture the niches, the Singapore state has been facing uphill battles to create local technopreneurship and has continued to depend on inward FDI. Although the Singapore state has been inspired by the Korean chaebol and nurtured large domestic business groups such as the government-linked corporations, they tend to engage in commercial expansion rather than technological deepening and have thus been unable to produce global innovative giants.

To support the strategic retreat, the Singapore state has gradually changed its approach to organize and manage technological, industrial and economic development. The technological and market uncertainties of both the biomedical industry and the clean technology industry have rendered a decentralization of expertise that has subsequently led a more horizontal distribution of authority in shaping science-based industrialization (Wong 2011), rather than a singular reliance on the bureaucratic commanding agency of the EDB and its allies (Tsui-Auch 2004). This has brought Singapore to resemble its counterparts, shifting from past practices of top-down command and control towards a decentralized approach to managing science and technology development, and to allowing a diversification of bets into recent new pickings. Moreover, the state has gradually reduced its ownership of and control over the government-linked corporations. As the government-linked corporations are increasingly commercially driven and involved in overseas acquisitions, the government has gradually reduced its stake in some of them including SingTel. In addition, these corporations have reduced their recruitment of
directors of the board and top management personnel from the civil service sector and increased that from the corporate sector (Tsui-Auch and Yoshikawa 2010). In the face of increasing nationalism in neighbouring countries, the Temasek Holdings announced the adoption of a ‘three-pronged strategy’ to meet the challenges that includes avoiding investment in ‘iconic’ companies, tying up with local partners and seeking minority stakes (Chua 2007).

**Conclusion**

In this chapter we have documented the technological and industrial development of Singapore in the past four decades with examples from three key industries – electronics/IT, biomedical and clean technology. We have shed light on the role of the state as a double-edged sword, both enabling and inhibiting such development. We argue that the strong developmental state has been instrumental in successfully establishing an electronic/IT industry for the manufacturing economy but has been facing severe challenges in developing science-based industrialization for the knowledge economy. The state’s venture into science-based industrialization has in turn reshaped its role in organizing science and technology as well as the economy. As shown in the analysis, the state has gradually made a strategic retreat in picking winners, changed its approach in organizing science-based industrialization and loosened its control over the government-linked corporations.

**References**


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