CHAPTER 7

Innovation Policy in Singapore

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7.1 | Introduction

Singapore has achieved rapid economic development through continuous industrial restructuring and technological upgrading. After independence in 1965, growth was largely driven by labour-intensive manufacturing by multinational companies. These companies were attracted to invest in Singapore by the business-oriented government policies, such as relatively low taxes, a productive labour force relative to its wages, harmonious industrial relations, and transparent and effective macroeconomic management. Following the success of labour-intensive industrialisation, subsequent industrial policies gave high priority to capital- and skills-intensive foreign direct investment. In addition, Singapore's rapid development as an important business, financial, transport, and communication services hub had provided important value-added to its gross domestic product by the late 1980s. Nonetheless, the manufacturing sector remains a very important and strategic element of Singapore's national innovation policy and its drive for technological development and skills upgrading.

Singapore has made significant progress in developing its science, technology, and innovation capability over the more than 50 years since political independence in 1965. This effort was initially based on an evolving national system that emphasised attracting and leveraging multinational companies to transfer increasingly advanced technological operations to Singapore, and developing infrastructure and human resources to absorb and exploit new technologies rapidly. In the 1990s, Singapore started to shift towards a more balanced approach, with increasing emphasis on developing its indigenous research and development (R&D) and innovation capability.

To position Singapore as a knowledge-based, innovation-driven economy, the government started to invest in R&D to develop capabilities, infrastructure, and talent. As a result, 'Research, Innovation, and Enterprise' has become the theme of Singapore's national system to support the continuum from research to value capture.

In 2016, the government unveiled the Research, Innovation and Enterprise 2020 Plan for an investment of S$19 billion over five years starting from 2016.[1] This was an 18% increase over the previous five-year tranche, aiming to more effectively leverage science and technology to build the innovation capacity of the private sector and address national challenges. Under the plan, funding for 'White Space', which refers to emerging research, innovation, and enterprise activities, will be bumped up to S$2.5 billion, a more than 50% increase from 2015. The National Research Foundation will also build a renewal mechanism through White Space to ensure that resources are reprioritised to deserving areas, such as those of national need, economic opportunity, and competitive capabilities.

Another important aspect is the doubling of the percentage of open competitive funding for public R&D to S$4 billion to find the best ideas and most deserving needs in four 'technology domains' – advanced manufacturing and engineering, health and biomedical sciences, services and digital economy, and urban solutions and sustainability – and in academic research (Government of Singapore, 2016). Since 2006, public expenditure on R&D has increased by 9.1% annually and reaching S$3.7 billion in 2015. Singapore's research intensity continues to rise, increasing from 2.2% of gross domestic product in 2014 to 2.4% in 2015 (Government of Singapore, 2015). Details of expenditures and other characteristics of R&D are in the Appendix.

The Research, Innovation and Enterprise 2020 Plan seeks to support and translate research into solutions to national challenges, build up innovation and technology adoption in companies, and drive economic growth through value creation. The sixth five-year roadmap for research, innovation, and enterprise will be more targeted in its funding approach as the National Research Foundation looks to capitalise on technology in which Singapore has a comparative advantage as well as build capabilities in areas deemed to have a greater national need. Conceptually, this is intended to focus efforts in areas where national need, economic opportunity, and competitive capabilities intersect, as well as to create value from R&D investments. Instead of broadly categorising funding into 'private R&D' and 'public R&D' as in the past, the new approach focuses on the four primary technology domains.

1 The plan was unveiled by Prime Minister Lee on 16 January 2016.

The domains seek to deepen the technological capabilities and competitiveness of Singapore's manufacturing and engineering sectors, advance human health and wellness, and leverage the country's digital capabilities to raise productivity and meet national priorities, such as developing a reinforced cyber security infrastructure and system to fend off cyber threats. The four domains will be supported by three 'cross-cutting programmes' – academic research, manpower, and innovation and enterprise – that aim to ensure excellent science and a strong pipeline of manpower and value creation.

7.2 | Conceptual Framework

The focus of this chapter is to describe and analyse the diffusion of knowledge over successive economic restructuring and technological development phases in Singapore's industrial development. This process can be observed through the upgrading of an existing industrial cluster, as in the case of marine offshore engineering, and the creation of a new biomedical science cluster. Singapore has achieved significant technological capability development, particularly since 2001. R&D was quite limited in the late 1980s, with a gross expenditure on R&D (GERD) to gross domestic product ratio of only 0.86% in 1987. However, the government subsequently increased the GERD, and by 2015, Singapore's GERD had reached a high of S$9.5 billion (Government of Singapore, 2015). This was supported by increased business expenditure on R&D, which reached S$5.8 billion in 2015 (Government of Singapore, 2015). However, important though it is, increased expenditure on R&D is only part of the story. More significant is how increased expenditures for R&D are managed, coordinated, and diffused to form innovation clusters. A conceptual framework for analysing the link between innovation and knowledge-based industrial clusters was applied in Singapore to develop electronic, logistics and transportation, business and finance, marine offshore engineering, and biomedical and healthcare clusters.

A knowledge-based industrial cluster is one that derives significant value creation from the creation and use of advanced knowledge. These two elements are important and necessary, requiring both the creation of knowledge-intensive output and the use of knowledge-intensive processes in generating this output. Theoretically, a knowledge-based cluster has several components. First, a knowledge infrastructure is required in terms of R&D institutes and universities as the lead generators of knowledge to conduct basic research and training. Second, links to lead users of knowledge are critical; without them, public research institutes and universities risk producing innovations that are irrelevant to industries. Third, for the cluster to be sustainable, critical knowledge-commercialising and innovating firms are required. Fourth, the cluster requires supporting industries and services. Fifth, the cluster must be supported by a regulatory framework and business environment in which to operate. These five components can be considered as the ecosystem for an industrial cluster to grow to become an innovation-conducive environment (Wong et al., 2010).

The main element of Singapore's innovation policy is the tripartite 'Home' strategy, which refers to 'Home for Business', 'Home for Innovation', and 'Home for Talent' as part of the innovation strategy. Home for Business provides an overall framework for the talent and innovation strategies. The Home for Business strategy extends to every industry, not just those of the modern innovation powerhouse. In other words, Singapore places as much emphasis on consumer goods manufacturing, electronics, chemicals, and energy as it does on information technology (IT) and digital media. The Economic Development Board (EDB) has become a one-stop shop that works to create the right conditions to attract talent and investment. When those conditions were lacking, Singapore has taken great pains to create them. Take the IT and Internet technology space, for example: the entrepreneurial scene in Singapore was barren in this area until recently.

The Home for Innovation entrepreneurial ecosystem is being created in Singapore. In 2015, it had more than 42,000 starts-ups, and almost 1 in 10 people of working age in Singapore was trying to start a company (Government of Singapore, 2016). The question is, why has Singapore not yet had a breakout of major start-up tech companies? Incubators, such as Block 71, are intended to produce them.

The Home for Talent strategy adopts Singapore's innovation strategy to respond to broad macro trends happening in global markets. Singapore has benefited from its geographic location close to rapidly emerging economies, such as China, India, and Indonesia. As a result, Procter & Gamble are making Singapore their regional hub for consumer and beauty products. Huge United States multinational companies, such as DuPont, General Motors, and Archer Daniels Midland, continue to make Singapore an important part of their growth strategy, attracted by Singapore's proximity to China and its ability to tap Asia's future growth. A strong commitment to science and education in Singapore means there is a constant influx of new talent for any multinational company looking to expand into Asia's rapidly emerging economies. Singapore's goal is to always be relevant for companies that see Asia as the source of fastest growth.

7.3 Key Processes in Developing Knowledge-based Clusters

7.3.1 Key knowledge-cluster components

Singapore adopts a flowchart approach to industrial cluster formation. This approach attaches high importance to systematic arrangement and consideration, and is based on the concept of economies of sequence, which dictates the order in which segments of the industry cluster are formed. Such an approach generates important positive externalities by establishing backward and forward linkages between industry and other economic sectors. To create a knowledge cluster, the following four components must be in place (Kuchiki and Tsuji, 2010).

Public knowledge infrastructure. This may involve creating new universities and public research institutes, restructuring existing institutions, or creating new programmes within them to prioritise the fields of research and education needed for the cluster under development. More concretely, Singapore has established the Biomedical Research Council (BMRC), which has seven research institutes and five research consortia under its umbrella, and the Science and Engineering Research Council (SERC), with seven research institutes and one centre. The BMRC and the SERC are under the Agency for Science, Technology and Research (A*STAR), which has also set up the A*Star Joint Council to facilitate interactions between the BMRC and the SERC to foster interdisciplinary and cross-council research. The physical proximity of the BMRC and the SERC is deliberate: the BMRC is in Biopolis and the SERC is in Fusionopolis, just 600 metres apart.

Inducements for private companies to cluster. The development of the private sector can take the form of both attracting foreign firms to set up operations in the country and nurturing local firms and industry to upgrade their knowledge intensity. The government has provided incentives to attract well-established international pharmaceutical firms to set up operations in Singapore and undertake joint research with public research institutions. For example, Procter & Gamble has vast investments in making Singapore a regional hub for consumer and beauty products, and Jurong Island is being redeveloped into an innovation showcase for energy and chemical firms, such as Exxon Mobil. Such links could take the form of anchoring foreign lead-user firms in the country, and then encouraging intra-firm technology transfer between the parent headquarters and the overseas subsidiaries of transnational companies.

A complementary strategy is to build international links through international R&D consortia, common technical standards coalitions, cross-licensing of technologies, or long-term supplier–buyer relationships.

Knowledge flows and network links among key actors in the cluster. This includes inter-sector networks, such as between universities, public research institutes, and private firms, as well as creating platforms and mechanisms for inter-firm collaboration within the private sector. Examples include R&D alliances and industry consortia.

A regulatory framework and business environment. A regulatory framework with rules and regulations that are transparent and fair to all stakeholders must be created and a competitive business environment established to facilitate and encourage creative efforts and innovation.

7.3.2 Role of the state in developing knowledge clusters

The state can play a significant role in facilitating the development of knowledge-based clusters through its policies and investment programmes. This can be seen in Singapore's industrial strategy since the start of industrialisation to present day innovation policy. Given the diverse strategies that can be adopted in the development of clusters, the strategic choices taken by the government, such as the choice of actors to promote and the timing of entry into emerging technologies, can have significant impacts on the resulting dynamics of cluster development.

In its choice of actors to promote, the state can focus on either local or foreign resources in developing the cluster. Through the EDB and A*STAR, the Government of Singapore has become the major focal point in attracting foreign firms and foreign talents to develop the selected clusters.

In terms of timing its entry into emerging technologies, the state can enter the global market while the technology is still in its infancy or wait until the market and technology are more mature. In the case of Singapore, most of the technologies are already developed and mature in Europe and the United States, but they are relatively new in Singapore and in Southeast Asia. Often, established technologies are adapted to meet emerging regional demand for the products and services.

In developing knowledge clusters, the government also faces the choice of upgrading the knowledge intensity of existing clusters or creating entirely new clusters for emerging technologies. Regardless of the strategy adopted, there will be common elements in the strategies used as the key processes for cluster development are common to both new and existing clusters. However, the timing of government intervention, and therefore the specific role of the state, would be different depending on the maturity and nature of the cluster to be developed. Developing an offshore marine engineering cluster and integrated logistics hub is an example of a more mature cluster that has evolved from the shipbuilding and repair industry and transport and air services. Developing knowledge in the biomedical sciences, on the other hand, requires an entirely new industrial cluster.

7.4 | Case Studies

7.4.1 Developing a mature cluster: The offshore marine engineering cluster

Singapore's offshore marine engineering cluster is based on an industrial cluster that has already become one of the world's leading hubs for offshore oil and gas platform production. Thus, the transformation of Singapore's maritime services cluster into the International Maritime Centre (IMC) involved upgrading the knowledge of existing industries. Singapore's maritime cluster is well established in one of the world's most important port and shipping locations. The impetus to upgrade and enhance the IMC was to position Singapore as a leading international maritime centre in the wider Asia region.

Singapore's maritime cluster comprises two sectors: core maritime transport and the non-core maritime sectors, including services that support marine transport. The core maritime transport sectors are those that derive their revenue entirely from maritime-related activities. Non-core sectors are those for which maritime activities form only a part of their total operation. The IMC has experienced strong growth in value-added, employment, and labour productivity since the government launched the upgrading of the offshore maritime cluster. The continued growth of Singapore's maritime cluster has been achieved despite increasing regional and global competition. This can be attributed to an increase in labour productivity and knowledge intensity in key maritime sectors.

The maritime engineering industry, which comprises the shipbuilding and repair sectors, has upgraded technological capabilities and increased knowledge intensity in the maritime cluster. Traditionally, this sector was mainly involved in providing repair and overhaul services to vessels calling at the Port of Singapore. The industry was able to transform itself by successfully diversifying into offshore oil and gas construction and marine engineering services. With strong assistance and incentives provided by the state, Singapore has broadened its traditional shipbuilding activities to become a global leader in the offshore construction business. In addition, the marine industry (i.e. non-core maritime sector) that has achieved strong growth through increased productivity and knowledge intensity is bunkering and logistics services. Growth in this sector has also provided an impetus for the development of maritime finance and insurance services. How has Singapore implemented its innovation policy to upgrade the maritime industry so effectively?

The Maritime and Port Authority of Singapore (MPA) was appointed as the 'champion agency' for the comprehensive development of Singapore from primarily a sea-transport hub into the leading comprehensive integrated IMC in Asia. At the outset, the government, through the Ministry of Transport, spelled out a vision of Singapore as the leading maritime hub in Asia with a vibrant IMC cluster that not only complements Singapore's hub port status but also serves as an additional engine of growth for Singapore's economy.

The MPA plays a leading role in IMC development in the context of a multi-agency coordination approach. The institutional framework for IMC development involves several ministries and government agencies as well as industry participation through associations and the Singapore Maritime Foundation. The presence of multiple agencies and stakeholders ensures an integrated development approach. Two strategic initiatives and continued port upgrading in infrastructure and facilities are required to steer the development of Singapore as an IMC. First, the MPA as the champion agency has the task of overseeing the expansion of Singapore's maritime activities from core port and shipping services into bunkering, ship brokering, logistics support, and surveying activities. Second, maritime ancillary services are developed, such as marine insurance, maritime finance, and maritime legal services. To achieve these interrelated strategic initiatives, the continued vibrancy of the port and shipping services sectors is critical, and investment in port upgrading and technological improvement must be undertaken simultaneously.

Diversification into new areas has opened up opportunities for R&D and IT projects and provides additional incentives to attract maritime ancillary services. The MPA has instituted a number of initiatives in line with the Ministry of Transport's vision. In this context, the MPA has initiated a memorandum of understanding between the MPA and the Research Council of Norway, which has an excellent reputation in maritime-related research, education, and training. This framework provides for the MPA and Research Council of Norway to collaborate on several business- and user-oriented maritime R&D and education and training projects. The scope of the memorandum of understanding includes a broad range of activities, such as exchange programmes and industrial attachments, education and training courses, and cooperation in commercialising the results of the maritime R&D and education and training projects.

In addition to establishing memoranda of understanding with well-known foreign institutions in maritime R&D, the MPA launched and administers the Maritime Innovation and Technology Fund, which is designed to support development programmes under the Maritime Technology Cluster Development Roadmap. The fund supports the following programmes and schemes:

(i) The Trident Platform. This is a platform for developing and testing, or 'test-bedding', maritime innovations. The programme supports companies and tertiary and research institutions in undertaking maritime-related R&D and innovation development using Singapore's port and maritime facilities as test-beds for innovation.
(ii) The Maritime Seed Fund. The fund targets new and emerging maritime companies seeking to bring technologies or innovation from concept to commercialisation, as well as established maritime technology companies seeking to embark on further R&D, set up facilities in Singapore, or venture overseas.
(iii) Joint tertiary research institute and MPA research programmes. Universities and polytechnic students are encouraged to participate in the joint research programmes of the MPA and tertiary research institutes.
(iv) Technology professorships. Universities are encouraged to provide technology resources for industries' contributions through dollar-for-dollar matching governmental funding.
(v) The Maritime Industry Attachment Programme. This programme aims to immerse engineering, IT, and science students from tertiary research institutes in the maritime industry. Students' suggestions on technology development and innovation will be awarded prizes if they are accepted. Postgraduate R&D projects will be funded by the Maritime Innovation and Technology Fund.

Singapore's innovation policy and programmes have been very successful in diversifying traditional shipbuilding and repair into offshore construction and marine engineering services. The country has emerged as one of the world's leading offshore and marine engineering clusters, boasting 70% of the global market share for the conversion of floating production storage and offloading vessels and 7% of the world market share in jack-up rig construction (Wong et al., 2010). This remarkable success in innovation policy and strategy is based on standard key principles and processes in developing knowledge-based clusters and industrial development. It should be noted, however, that without suitable institutions, legal framework, and a capable and effective public administration, applying these standard principles and processes might not yield the level of success experienced by Singapore. Innovation policy and processes must be implemented under a favourable ecosystem, in a sustainable manner, and by competent public administrators to promote competitive and entrepreneurial business sectors. Every segment of the process is important and plays a different strategic role at different stages while consistently moving towards the achievement of a common vision and objectives.

7.4.2 Creating a new cluster: The biomedical sciences cluster

From the start of its industrial development, Singapore has always relied on attracting foreign direct investment from global multinational companies and leveraging it to exploit technologies and know-how created by developed countries. This strategy has worked in developing electronics manufacturing and information technologies. The same leveraging strategy was used in developing the pharmaceutical industry, where it appears to have been equally effective in terms of total value-added to manufacturing output.

The vision and mission in developing a biomedical sciences cluster were conceived as a strategic shift to diversify from a high dependence on IT and electronics manufacturing. The objective is for life sciences to become a key pillar of Singapore's economy, together with electronics, engineering, and chemicals. The vision is to transform Singapore into a major hub of biomedical sciences with world-class capabilities across the entire value chain, from basic research to clinical trials, product and process development, full-scale manufacturing, and healthcare delivery. The state's role remains a critical factor both in upgrading the existing cluster in offshore marine services and in developing the new biomedical sciences cluster. However, much greater investment and effort are required to develop the biomedical sciences cluster.

The two government agencies responsible for establishing the biomedical sciences cluster are A*STAR and the EDB. A*STAR, through the BMRC, concentrates on putting in place the appropriate policies, resources, and research and education architecture that will build biomedical science competencies internally, including funding and supporting public research initiatives. The EDB is responsible for bringing in investments and generating long-term economic value in the sector. The EDB's Biomedical Sciences Group, charged with developing industrial, intellectual, and human capital in support of biomedical sciences, and Bio*One Capital, charged with functioning as an investment arm, work together to attract biomedical sciences companies to establish R&D operations in Singapore and develop the local biomedical sciences manufacturing sector.

Due to the lack of an existing local biomedical sciences cluster, the government has tapped extensive international biomedical sciences talent to develop the cluster. The Biomedical Science Executive Committee, which leads the initiative, is advised by the International Advisory Council, comprised of eminent scientists from the global scientific community. Another high-level advisory body, the Bioethics Advisory Committee, was formed to develop recommendations on the legal, ethical, and social issues of human biology research. Its recommendations have led to a regulatory environment in Singapore that is broadly supportive of biomedical sciences. Clear legal support for stem cell research, combined with compliance with strict international guidelines, provides Singapore with a competitive advantage in stem cell research, particularly in dealing with the National Institutes of Health in the United States, which allows the federal government to fund research that uses Singapore-produced stem cells. After 15 years of consistent cluster development and innovation, Singapore is ranked as one of the leading centres for biomedical sciences, particularly on stem cell research.

The key elements of Singapore's strategy for biomedical sciences hub development are as follows:

Attracting foreign pharmaceutical firms. Through the EDB, Singapore has successfully attracted world-class pharmaceutical multinational corporations to carry out manufacturing, R&D, clinical trials, and other knowledge-intensive services. All the largest pharmaceutical manufacturing firms operating in the cluster are foreign majority-owned. To move these foreign investments into the higher-value-added segments of the biomedical industry value chain, the EDB encourages foreign companies to set up R&D or clinical research operations in Singapore.

This is facilitated by easy access to resources from public research institutes and universities. An important emerging branch of medical research is 'translational research'. This is a new approach to the development of drug treatments that attempts to connect basic research directly with patient care. Singapore's biomedical sciences development has moved beyond establishing basic life sciences infrastructure and industry to developing translational and clinical research. Recent foreign investment from leading pharmaceutical firms has been directed to this segment.

Developing physical infrastructure. Singapore has developed integrated physical infrastructure to house the biomedical sciences research cluster. 'Biopolis', as the cluster is named, is dedicated to biomedical R&D activities and designed to foster a collaborative culture among the institutions and with the National University of Singapore, the National University Hospital, and Singapore Science Park. Biopolis also provides integrated housing and recreation facilities for the many resident foreign scientists. The government hopes that creating the cluster will encourage informal networks for knowledge sharing to flourish, and accelerate the growth of a critical mass of biomedical expertise in Singapore and an R&D hub for the Asian region.

Locating public research institutes in the cluster. Singapore's seven public research institutes all have a presence in Biopolis. This is intended to attract biomedical multinational corporations, start-ups, and support services, such as lawyers and patent agents, to locate there.

Attracting foreign talent and training young local talent. Attracting foreign talent has become a major thrust of the government's biomedical sciences cluster strategy. The strategy is to attract internationally well-known scientists ('whales') to head research in biomedical sciences in public research institutes. In turn, these renowned scientists attract young scientists ('guppies') locally and globally to work under their leadership (the 'whales and guppies approach'). In addition, the government sends top students from local institutions to leading research institutes all over the world. Scholarships provided by A*STAR are given to a wide range of undergraduate and graduate students and medical specialists to study biomedical sciences. In the long term, it is expected that local universities and public research institutes will be bolstered by their alliances with established world-class research institutes and can grow their own bioscience human resources capabilities.

Promoting biotechnology firms, biomedical start-ups, and a venture capital industry. The measures to create a vibrant biomedical sciences cluster in Singapore are intended to lead to the promotion of technology commercialisation activities through start-ups and spin-offs from the public research institutions and universities. The availability of venture funding and financial resources for technology-based firms is a critical factor for supporting such activities.

The government has played a very important role in developing a specialised biomedical sciences venture capital industry. Since Singapore had little expertise and experience in venture capital, it was particularly critical for the government to take a lead role in setting up a number of life-sciences-related funds. These were eventually centralised under Bio*One Capital, a private equity and venture capital firm dedicated to investments in the biomedical sciences industry. In addition to bringing overseas biomedical sciences investments to Singapore, the work of Bio*One and other support mechanisms has resulted in the emergence of a biotech firms sector in Singapore. This includes a number of spin-offs from local universities. The main focus area for dedicated biotech firms is drug discovery and development. These firms are still relatively small compared to those in leading biotech clusters around the world (Finegold et al., 2004).

Expanding clinical research capabilities in the healthcare sector. The first phase of Singapore's biomedical sciences development focused on establishing a foundation of basic biomedical research in Singapore. The second phase moved into the development of capabilities in clinical and translational research while continuing to strengthen basic science. In this regard, Singapore's tactical advantage in clinical research is its good healthcare system. Despite this advantage, there are still relatively few clinical trials taking place in Singapore as it does not have a large domestic market for pharmaceutical products. Recent developments show further advancement in clinical capabilities. The development of clinical research involves developing translational research, which aims to build links between basic science conducted by other public research institutes and clinical research programmes in Singapore's public hospitals, disease centres, and universities. Two other schemes recently initiated by A*STAR are the Singapore Translational Research Investigator Award, which aims to recruit world-class clinical scientists to undertake clinical and translational research in Singapore, and the Clinician Scientist Award, which targets top local clinical researchers with proven leadership potential in research. Progress in clinical research has been made possible by Singapore's good healthcare system and high medical standards.

Promoting links between R&D, universities, and the healthcare services sector. In the development of clinical and translational research capabilities, there has been a deliberate strategy of forming and promoting collaborations between clinical researchers and scientists in multiple agencies. The consortia, initiated by the BMRC to promote translational research links between biomedical sciences, public research institutes, and the healthcare sector, have been set up for this primary objective. The Singapore Cancer Syndicate, the Singapore Stem Cell Consortium, and the Singapore Immunology Network are some of the consortia established to promote translational research links in the biomedical sciences cluster. These consortia have engaged in joint training and the establishment of research infrastructure and links between local and overseas universities and well-known research centres.

The government played a vital role in initiating the biomedical sciences cluster and coordinating multiple agencies, as it did in the marine engineering cluster. It aimed to develop biomedical science through conducting investment and R&D promotion, developing public R&D institutes, and providing private sector companies with incentives for R&D, infrastructure development, and workforce development. Another important element for both clusters' development is attracting a critical mass of anchor firms or institutions to jump-start the clusters. In the offshore engineering cluster, firms in the traditional shipbuilding and repair sector were diversified into offshore construction activities. For the biomedical sciences cluster, foreign pharmaceutical multinational firms were given huge incentives to establish operations for knowledge-intensive services. In addition, the building of a critical mass in close proximity to the BMRC at Biopolis and the SERC at Fusionopolis, within 600 metres of one another, is deliberately designed to promote interdisciplinary research activities and other interactions.

However, the strategy and intensity of the government's role were different in developing an existing development cluster compared to a completely new cluster, and the role played by R&D and innovation varied depending on the stage of cluster development. For the biomedical sciences cluster, the establishment of R&D capabilities, the generation of intellectual property, and the subsequent commercialisation were critical right from the start. By contrast, the development of the marine offshore engineering cluster started with manufacturing, learning-by-doing, and the gradual accumulation of tacit process knowledge and innovation capabilities; and the role of public R&D institutions and the creation of intellectual property were not critical early on. Because early-stage start-ups are the key drivers for biomedical sciences, the availability of venture capital and global talent were more critical than foreign investment to build the expertise needed. For the marine offshore engineering cluster, leveraging the local production base was more effective in stimulating cluster growth.

Therefore, the degree of success in developing the marine offshore engineering cluster is more evident and cost effective compared to developing biomedical sciences, which requires a more complex process and hinges on global market growth opportunities rather than local and regional ones.

7.5 | Conclusion

Singapore's experience in developing industrial clusters clearly shows that it is possible to accelerate the development of knowledge-based industrial clusters through innovation and effective public policy.[2] The case studies of marine offshore engineering and biomedical science cluster development suggest that cluster development is possible through a coordinated, strategic approach involving multiple government agencies and investment sustained over a long period of time. Innovation development through industrial clusters is not based on straightforward principles and rules. Rather, it is critically dependent on multiple factors, such as the nature of the technologies or processes involved, the market environment, and a conducive 'innovation ecosystem' of good governance to provide the required correct legal system, infrastructure, human resources development in education, and research both in the public and private sectors. In the case of Singapore, the government is the main driver and the critical element for the success of innovative knowledge-based development. In the next phase of innovation development, the involvement of private sector entrepreneurs will be critical to competitiveness and sustainability.

Singapore's National Innovation System is certainly the most advanced in Southeast Asia. As a small economy, the key challenge for Singapore is to move nimbly and strategically to stay ahead of regional competitors as they develop capabilities in selected science and technology clusters. Specifically, Singapore is dependent on its continuing ability to attract global talent, especially the innovative and entrepreneurial talent that is crucial to achieving the next level of its national innovation objectives.

2 This chapter's findings and conclusions are supplemented and reinforced with interviews with the BMRC at Biopolis and the SERC at Fusionopolis.

Empirical evidence shows that R&D investment in Singapore has had a significant impact on its total factor productivity performance in the last 20 years and established a long-term equilibrium relationship between R&D investments and total factor productivity (Ho et al., 2009). However, the lower estimated elasticity values show that the impact of R&D investment on economic growth in Singapore is not as strong as that of members of the Organisation for Economic Co-operation and Development (Ho et al., 2009). This suggests that Singapore still has some way to go to catch up with other advanced industrial countries in terms of R&D productivity. In other words, Singapore must not only increase its level of R&D intensity, but, equally important, it must also be more efficient in exploiting domestic R&D with a view to increasing its value creation through enterprise, especially in the private sector.

What lessons can the member states of the Association of Southeast Asian Nations (ASEAN) learn from Singapore's experience? Each ASEAN Member State has its own unique approach to developing and managing its innovation policy based on its social, political, and economic characteristics and stage of development. However, there are some basic common denominators that less-developed member states can learn from Singapore's rapid development and experience in planning and managing its remarkable innovation development. The existence of a strong and consistent higher level of political leadership in planning, formulating, financing, and managing successive changes in innovation policy is a necessary but not sufficient condition. Successful innovation also requires a complex ecosystem of effective institutions, laws, rules, and regulations that are managed by able and effective public officials and strongly supported by the private sector in a competitive market environment. The involvement of an entrepreneurial private sector is another indispensable element for sustainable and competitive innovation policy, particularly at the later stage following the pioneering public sector outlays in innovation infrastructure and human resources acquisition.

In projecting Singapore's future innovation path, the government must be more efficient in allocating resources for innovative knowledge-based development. For example, in the Global Innovation Index 2015, Singapore was ranked in seventh place, but in terms of the innovation efficiency ratio, which shows how much output a country is getting for its inputs, Singapore ranked poorly (Yahya, 2014). While the government has played a vital and significant role in guiding science and technology capability development as an integral part of its overall economic development strategy, the emergence of a more vibrant technological entrepreneurial community is likely to be critical to Singapore's continuing transition from technology adopter to innovator. As a small economy, the key challenge is for Singapore to move continually upward in industrial development through an innovative knowledge-based industrial cluster strategy.

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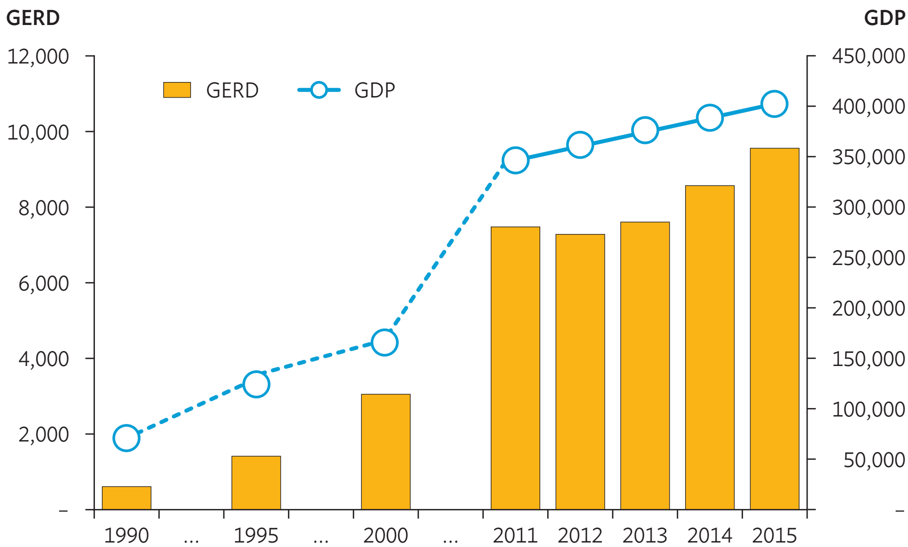
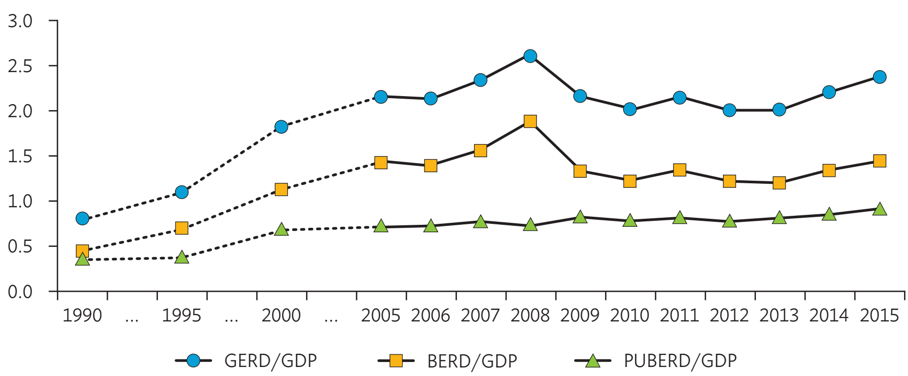
Figure A7.1: Gross Domestic Product Growth and Gross Expenditure on Research and Development, 1990–2015 (S$ million)



GDP = gross domestic product, GERD = gross expenditure on research and development.

Source: National Survey of Research and Development in Singapore, 2015 (published in December 2016). https://www.a-star.edu.sg.

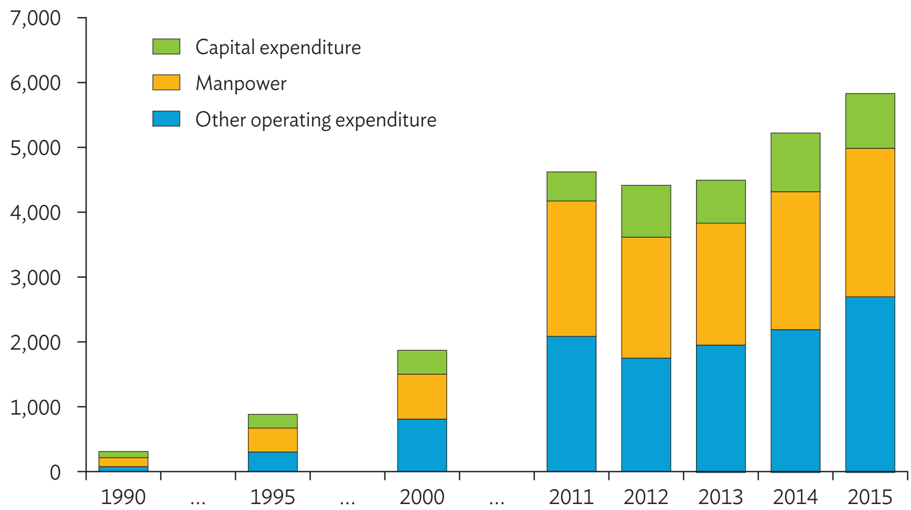
Figure A7.2: Gross Business and Public Expenditure on Research and Development as a Percentage of Gross Domestic Product, 1990–2015 (%)



BERD = business expenditure on research and development, GDP = gross domestic product, GERD = gross expenditure on research and development, PUBERD = public expenditure on research and development.

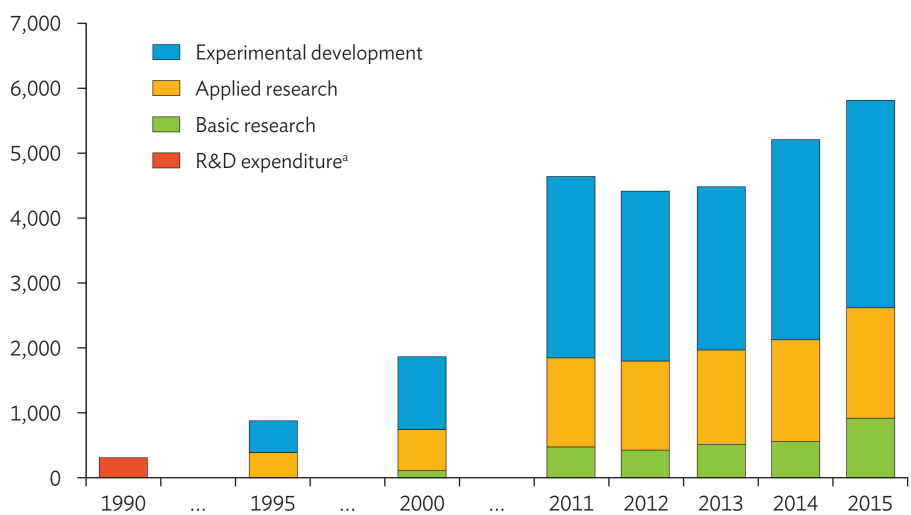
Source: National Survey of Research and Development in Singapore, 2015 (published in December 2016). https://www.a-star.edu.sg.

Figure A7.3: Business Expenditure on Research and Development by Type of Cost, 1990–2015 (S$ million)



Source: National Survey of Research and Development in Singapore, 2015 (published in December 2016). https://www.a-star.edu.sg.

Figure A7.4: Type of Business Expenditure on Research and Development, 1990–2015 (S$ million)

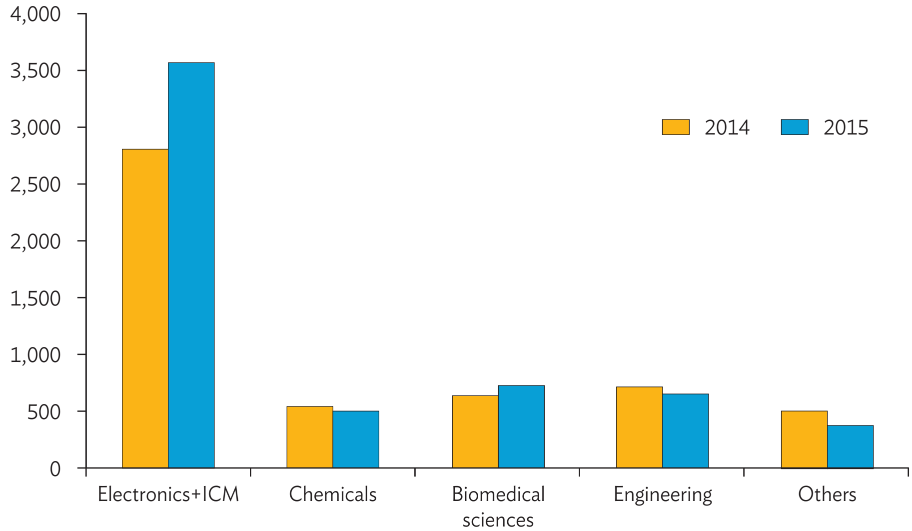


R&D = research and development.

[a] Expenditure data not collected in the same manner in 1990.

Source: National Survey of Research and Development in Singapore 2015 (published in December 2016). https://www.a-star.edu.sg.

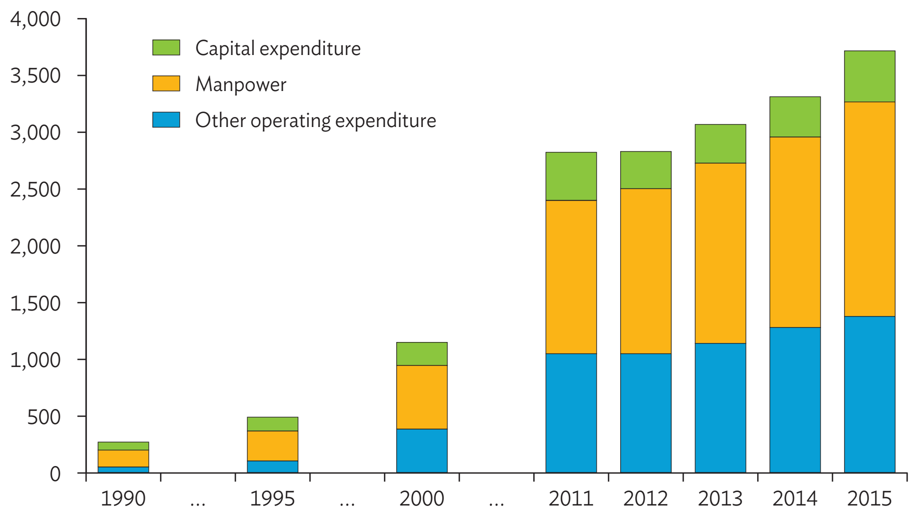
Figure A7.5: Business Expenditure on Research and Development by Fields of Science and Technology, 2014–2015 (S$ million)



ICM = infocommunications and media.

Source: National Survey of Research and Development in Singapore 2015 (published in December 2016). https://www.a-star.edu.sg.

Figure A7.6: Public Expenditure on Research and Development by Type of Cost, 1990–2015 (S$ million)



Source: National Survey of Research and Development in Singapore 2015 (published in December 2016). https://www.a-star.edu.sg.