UNIVERSITY OF CAMBRIDGE

Cambridge Industrial Innovation Policy

Singapore's Biomedical Cluster

Lessons from two decades of innovation and manufacturing policy

An innovation cluster case study prepared by the Policy Links Unit

February 2021

Contents

EXECUTIVE SUMMARY

Since 2000 Singapore has managed to shift its positioning from a pharmaceutical manufacturing outpost to a location for biomedical activities across the whole innovation and manufacturing value chain. This has been supported by a coordinated, proactive and patient policy that prioritised access to funding, skilled people and infrastructure provision, underpinned by a supportive regulatory environment.

In 2000 the Singaporean government launched a strategy to develop a biomedical industry within Singapore, and in late 2003 it launched Biopolis, a purpose-built campus, which has become an example of global best practice in the formation of an innovation cluster.[1] With a clear focus on biomedical sciences, the early stages required the development and attraction of scientific talent and proactive pursuit of FDI, while the more recent phases have seen the attractive effects of Singapore's biomedical cluster materialise, with many companies locating manufacturing, research and management activities in the country.

Since 2000 the biomedical manufacturing industry has seen fast employment growth (7.77%) in comparison with the overall manufacturing sector (0.68%) and the Singapore economy as a whole (3.14%). This reflects the significant growth in this sector – in 2000 there were no biological drug manufacturing sites in Singapore,[2] while by 2019 there were an estimated eighteen biopharmaceutical manufacturing plants in Singapore.[3]

TABLE 1 – SUMMARY OF KEY INDICATORS OF SINGAPORE'S BIOMEDICAL INDUSTRY, 2019, (UNLESS OTHERWISE SPECIFIED)

	Total Economy	Manufacturing Sector			
			Biomedical		
				Pharmaceutical and Biological	Medical Technology
Manufacturing value added (% of GDP)		£55.21bn (19%)	£11.12bn (4%)	£7.42bn (3%)	£3.70bn (1%)
Value added growth, compound annual rate (2000–2019)	5.12%	5%	9%	8%	12%
Jobs (% of country total)	3.78m (100%)	486,100 (12.8%)	24,384 (0.64%)	8,601 (0.22%)	15,782 (0.42%)
Growth in jobs (2000–2019)	3.14%[a]	0.68%	7.77%	8.19%	7.56%

Source: own elaboration based on Singapore's EDB Department of Statistics. Department of Statistics Singapore (2020). Singstat.

The efforts to create a biomedical manufacturing sector in Singapore are widely regarded as an economic success. As of 2019, the biomedical manufacturing sector represents 20% of total manufacturing value

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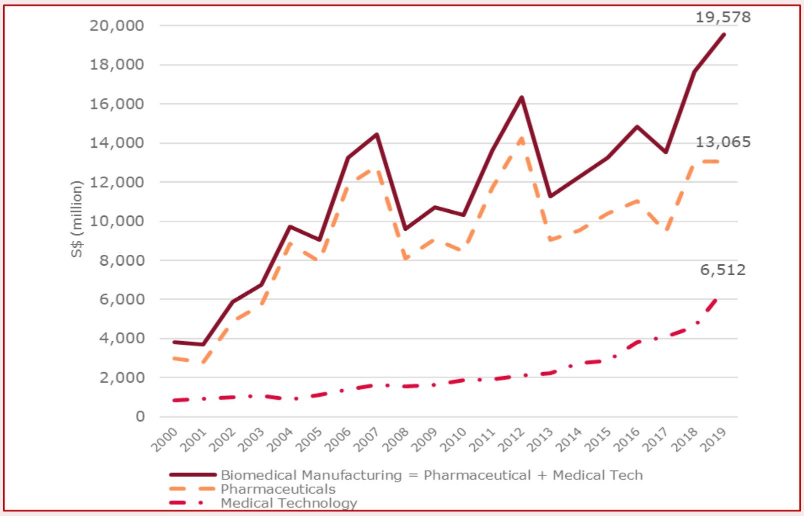
[1] Esmaeilpoorarabi et al. (2018). Place quality in innovation clusters: An empirical analysis of global best practices from Singapore, Helsinki, New York, and Sydney. *Cities, 75*, pp. 156–168.
[2] Beh (2011). Making medicine, saving lives in Chan, Chin Bock (2011). *Heart Work 2: EDB & partners: new frontiers for the Singapore economy*. Singapore: Straits Time Press: Singapore Economic Development Board.
[3] Own research. See Table 4 – Biomedical companies in Singapore – for a table of biopharmaceutical manufacturing sites.

added (S$19.57bn, or £11.14bn), equivalent to 4% of Singapore's GDP. From 2000 to 2019, biomedical manufacturing was the fastest-growing manufacturing sector, with a compound annual growth rate (CAGR) of 9% (compared to a 5% average growth rate for the whole of Singapore's manufacturing sector). Within this sub-sector, the medical technology manufacturing segment experienced a 12% CAGR in added value during the same period.

FIGURE 1 – SINGAPORE: VALUE ADDED IN BIOMEDICAL MANUFACTURING, 2000–2019



Source: own elaboration based on Singapore's EDB Department of Statistics. Department of Statistics Singapore (2020). Singstat.

This case study examines the supporting policies used to develop Singapore's biomedical industry against the success factors normally associated with innovation clusters, deriving policy implications from these. To do this, it focuses on the physical infrastructure that formed the centre of the cluster developed by the Singaporean government in the TUAS Biomedical Park and Biopolis precinct. It also provides a history of Biopolis over the first two decades, since its inception in 2000, within the context of the wider biomedical manufacturing sector.

The specific policy measures that supported the strategy included government-sponsored global headhunting of the world's top scientists, publicly funded research institutes and a biomedical science park, scholarship programmes for human resource formation in leading global and local universities, government venture capital for private-sector industrial projects and holistic integration of research activities, as well as more traditional tax incentives and IP frameworks.

Despite already being a manufacturing hub for pharmaceuticals, the attraction of activities across the biomedical manufacturing chain, including R&D, supported increased investments in basic science. Today, in R&D employment, Singapore employs five times more biomedical researchers per capita than the US – in 2018 Singapore boasted 128 biomedical researchers per 100,000 residents, compared to the US's 24 biomedical researchers per 100,000 residents.

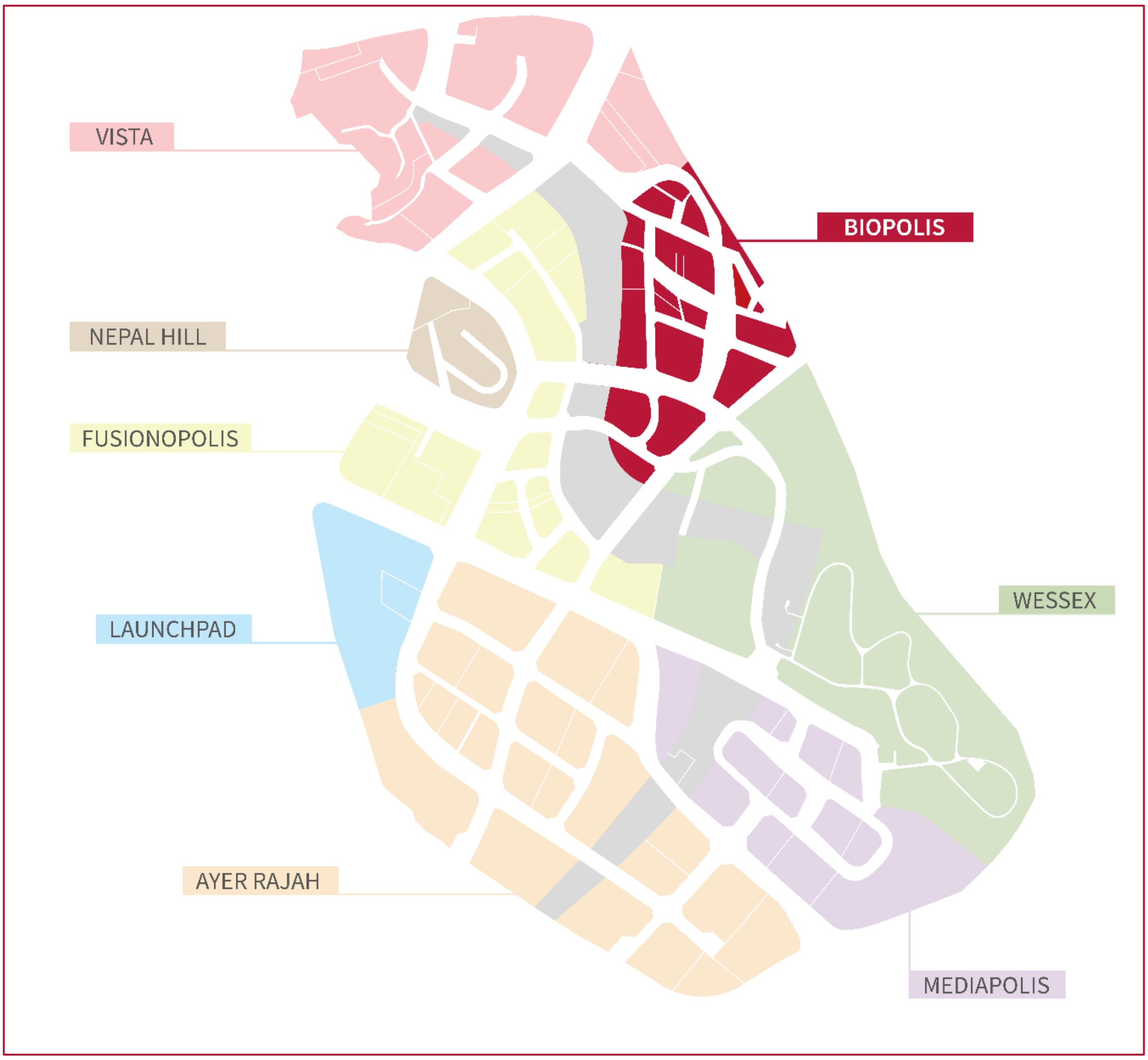
Through this whole-system approach, Singapore was able to meet and exceed its value added targets for the biomedical manufacturing industry, which were set every five years up to 2015. Similarly, biomedical manufacturing job targets were reached at each juncture. However, global targets to increase R&D to a proportion of GDP were not met, and the ratio of public to private spending on R&D in the biomedical sector still lags behind the R&D average.

INTRODUCTION

This case study focuses on the biomedical sciences industry in Singapore between 2000 and 2020. A central element of the industry is Biopolis, a new site created in 2003 that has been the nucleus for growth in the biomedical manufacturing sector in Singapore.

Half an hour by subway from Singapore's Central Business District (CBD), Biopolis is co-located in a site known as one-north with Fusionopolis, a technology hub focused on physical sciences and engineering R&D and ICT, the media hub Mediapolis, the training and talent development centre at Nepal Hill, the start-up hub LaunchPad, the corporate and business cluster Vista, a mix of electronics design, analytics and factory space in Ayer Rajah, and the residential Wessex area.[4][5]

FIGURE 2 – ONE-NORTH ESTATE, INCLUDING BIOPOLIS.



Other sites of interest in the Singaporean biomedical context include Tuas Biomedical Park, launched in 1997 as a manufacturing cluster, and the MedTech Hub at Tukang Innovation Park, located approximately halfway between the two, which was launched in 2012.

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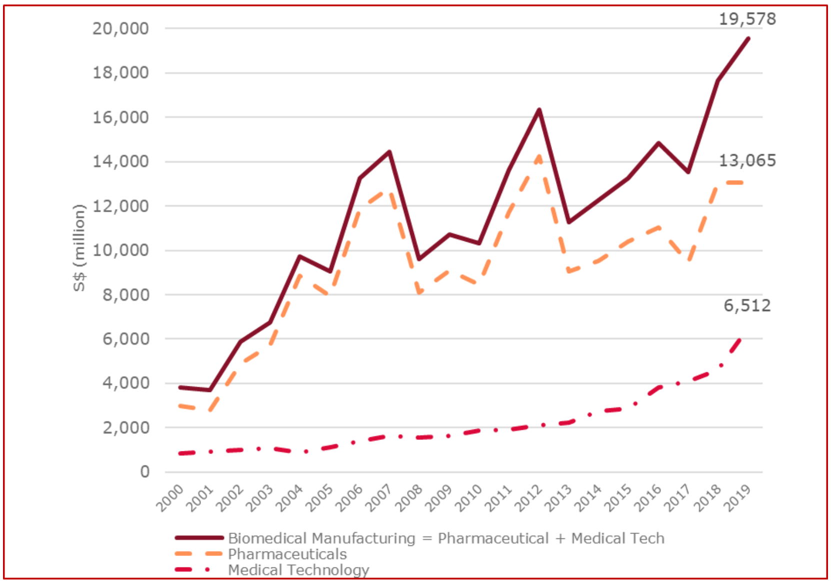
[4] JTC (2019). A guide to one-north.
[5] JTC (2020). One-North. *JTC, Projects and properties.*

FIGURE 3 – LOCATION OF BIOMEDICAL HUBS IN SINGAPORE

For the purposes of this report, biomedical manufacturing is defined as the combined output of the pharmaceutical and medical technology sectors.[6] Medtech is broadly defined as any technology that can be used in a health or care setting, for example, pacemakers, diagnostic tests, contact lenses and AI-assisted health care. In 2019 biomedical manufacturing employed 24,384 people, 65% in medical technology manufacturing and 35% in pharmaceuticals. Together, the value add to Singapore's GDP was just under S$20 billion in 2019.

FIGURE 4 – SINGAPORE: VALUE ADDED IN BIOMEDICAL MANUFACTURING, 2000–2019



Source: Own elaboration based on Singapore's EDB Department of Statistics. Department of Statistics Singapore (2020). Singstat.

At the start of its biomedical strategy in 2000, Singapore had some pharmaceutical manufacturing capability, and yet there was limited local experience in manufacturing biomedical products. To mitigate this, Singapore's Biomedical Sciences Executive Committee was advised by the International Advisory Council, comprising eminent scientists from around the world.

[6] See Appendix 1 for more information on the sector classification used to define biomedical manufacturing.

The government of Singapore took a proactive role in developing the country's biomedical manufacturing industry. This involved a concerted state initiative through the Economic and Development Board (EDB), Agency for Science, Technology and Research (A*STAR), the Ministry of Trade and Industry, the Ministry of Education, the Ministry of Health and the National Research Foundation.[7] Of these, the EDB and A*STAR through the Biomedical Research Council (BMRC), which was established in 2000, played pivotal roles.

Box 1: What is the "bio" in biopharmaceuticals?

Biologics (or biologicals) are defined as any therapeutic agent manufactured in living systems such as microorganisms, or plant and animal cells, and they include blood and blood components, vaccines and other biomolecules extracted directly from natural sources. Insulin is a well-known example. Biopharmaceuticals, a sub-segment of biologics products, are defined as substances produced in living systems by biotechnology and used for therapeutic processes or *in vivo* diagnostics. Pharmaceuticals, by contrast, are usually smaller molecules, generally synthesised using chemical reactions.

While A*STAR focused on policies, resources and research and education architecture that would build biomedical science competencies, the EDB was responsible for bringing in investment and generating long-term economic value in the biomedical sciences sector,[8] mainly through the Biomedical Sciences Group and Bio*One Capital.[9] The remit of these two organisations was to attract biomedical sciences companies to establish R&D operations in Singapore and to develop the local biomedical sciences manufacturing sector.[10]

Tuas Biomedical Park, Biopolis and MedTech Hub were developed by the JTC Corporation, the lead agency in Singapore for the planning, promotion and development of industrial real estate. Founded in 1968, the JTC Corporation has a track record of developing industry to support Singapore's economic development.

Box 2: How does manufacturing biopharmaceuticals differ from pharmaceuticals?

Most biologic products are proteins, either in natural or modified form. Fermentation and cell culture are the dominant means of production for these drugs, followed by various isolation steps from the bioreaction and purification steps, leading to the required drug quality and safety. Therefore, after the production stage (fermentation and cell culture) in *bioreactors,* separation stages for purification follow the process. Typical separation stages include: *centrifugation* and *filtration* steps for the removal of cells and cell debris; and *chromatography* and *filtration* steps for purification.

By comparison, pharmaceutical products typically do not involve fermentation or cell culture, instead producing the active ingredient through chemical synthesis or extraction from non-living natural sources.

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[7] Fischer (2018). A Tale of Two Genome Institutes: Qualitative Networks, Charismatic Voice, and R&D Strategies—Juxtaposing GIS Biopolis and BGI. *Science, Technology, and Society, 23*(2).

[8] Wong et al. (2010). Industrial Cluster Development and Innovation in Singapore. *From Agglomeration to Innovation,* pp. 50–116.

[9] Bio*One Capital Pty Ltd was founded in 2001 as a wholly owned subsidiary of EDB Investments, the venture capital arm of the Singapore government's Economic Development Board (EDB).

[10] Finegold, Wong & Cheah (2004). Adapting a Foreign Direct Investment Strategy to the Knowledge Economy: The Case of Singapore's Emerging Biotechnology Cluster. *European Planning Studies*, Vol. 12, No. 7, pp. 921–941.

RESULTS

The results of Singapore's biomedical strategy lie at the core of its consideration as a case study; they can be evaluated by its contribution to economic indicators and innovation. From an economic perspective, there has been a clear increase in manufacturing value added and also clear growth in jobs in the sector. From an innovation perspective, assessments are more varied, and yet Singapore is generally seen as a competitive global innovation hub.

The economic contribution of the biomedical manufacturing is significant, contributing 4% (£11.12bn) to Singapore's GDP in 2019. Since 2000, the growth in biomedical manufacturing jobs has outstripped job growth in the economy, with the sector employing over 24,000 people in 2019. There have also been clear increases in value added growth – approximately 9% over this period – almost twice that seen in the wider manufacturing sector and the rest of the economy.

TABLE 2 – SUMMARY OF KEY INDICATORS OF SINGAPORE'S BIOMEDICAL INDUSTRY, 2019

All values for 2019, unless otherwise specified	**Total Economy**	**Manufacturing Sector**			
			Biomedical		
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Jobs (% of country total)	3.78m (100%)	486,100 (12.8%)	24,384 (0.64%)	8,601 (0.22%)	15,782 (0.42%)
Growth in jobs (2000–2019)	3.14%[a]	0.68%	7.77%	8.19%	7.56%
Research jobs[b]	36,246	14,988[e]	7,150	6,367	783
Research jobs[b] in private sector (% of total)	19,386 (54%)	10,481[e] (70%)	1,201 (17%)	894 (14%)	307 (39%)
Research jobs[b] in government and public research institutes (% of sector)	6,903 (19%)	2,242[e] (15%)	2,872 (40%)	2,791 (44%)	81 (11%)
Research jobs[b] in higher education (% of sector)	9,957 (27%)	2,265[e] (15%)	3,077 (43%)	2,682 (42%)	395 (50%)

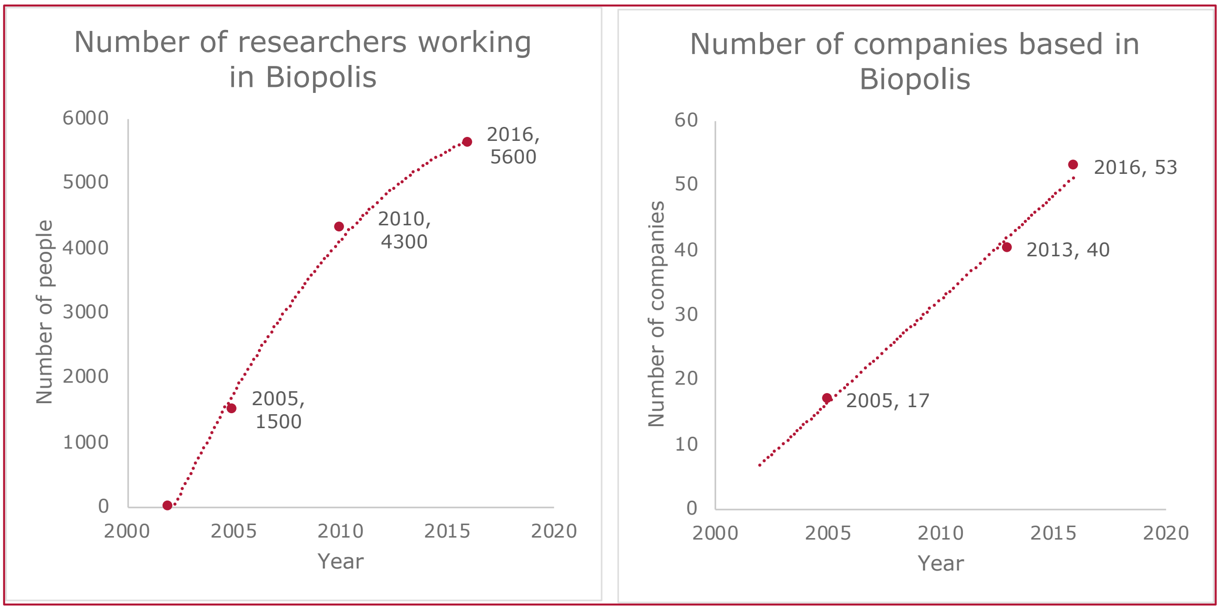
Note: e = estimate; a = data range 2001–2009; b = research scientists and engineers that are not postgraduate research students, non-degree researchers, technicians and supporting staff. Exchange rate used £1 = S$1.76.

Sources: own elaboration based on Singapore's EDB Department of Statistics (2020); A*Star 2019 national survey of R&D in Singapore; and World Bank data.

Between 2000 and 2020 Singapore managed to shift its positioning from a manufacturing outpost to a location for activities across the whole innovation and manufacturing value chain and an outpost for the Asian region.

The number of pharmaceutical and biological product manufacturing establishments grew from 25 in 2000 to 52 in 2018, representing an annual growth rate of 4% during this period. A significant proportion of these new sites are biological drug manufacturing – in 2000 there were no biological drug manufacturing sites in Singapore,[11] while by 2019 there were an estimated 18 biopharmaceutical manufacturing plants in Singapore.[12] Within Biopolis, there has been significant take-up by companies, as illustrated in Figure 5 (below).

FIGURE 5 – SINGAPORE: ESTIMATES OF NUMBER OF RESEARCHERS AND COMPANIES IN BIOPOLIS, 2005–2016



Source: These are estimates based on reports from a number of sources, including Gin (2005), Lim and Wei (2010), LiftStream (2012), Biospace (2013) and Muller (2017). Estimates after 2016 did not appear to be available.

The employment effects of the biomedical strategy can be evaluated by comparing the industry to employment in the electronics and ICT industry, where the anticipation of falling competitiveness and employment in the sector contributed to the drive of the Singaporean government towards biomedical sciences. Despite early concerns, electronics manufacturing still employed almost 70,000 people in 2015, compared to just under 20,000 in biomedical manufacturing.[13] While electronics manufacturing still contributes a larger share to the Singaporean economy than biomedical manufacturing,[14] the latter has become the second-largest manufacturing sector in the Singaporean economy in terms of value added.[15]

The number of biomedical science companies with R&D bases and manufacturing in Singapore overall, not just within Biopolis, is harder to ascertain, as estimates vary widely (Figure 6). There are an estimated

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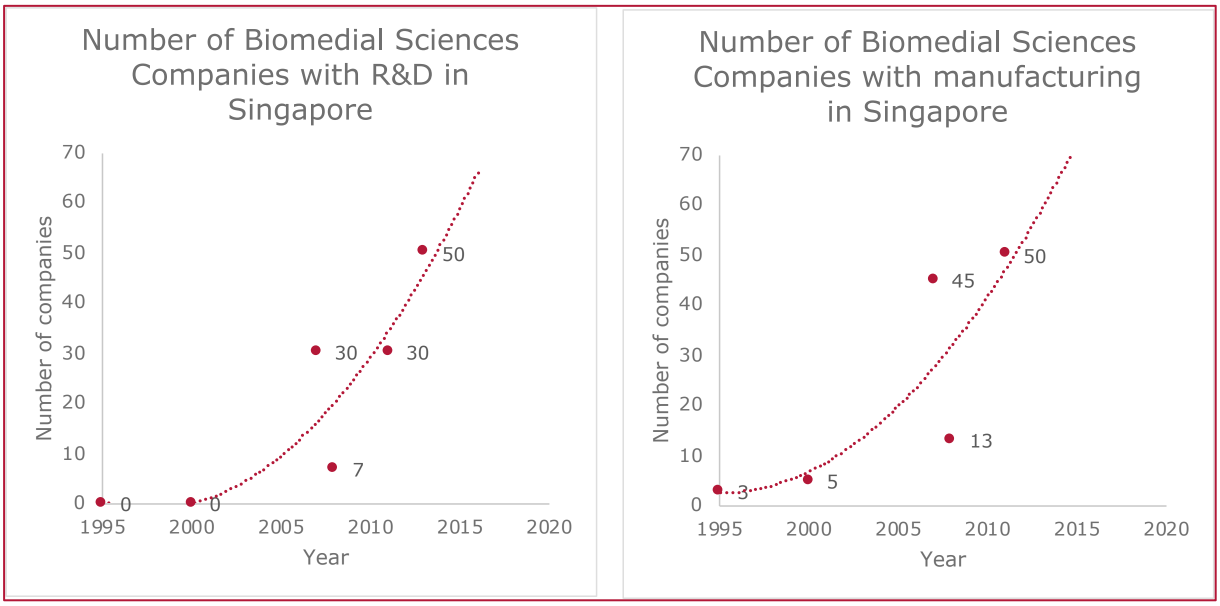
[11] Beh (2011). Making medicine, saving lives. In Chan, Chin Bock (2011). *Heart Work 2: EDB & partners: new frontiers for the Singapore economy*. Singapore: Straits Time Press: Singapore Economic Development Board.
[12] Own research. See Table 4 – Biomedical companies in Singapore – for a table of biopharmaceutical manufacturing sites.
[13] Ministry of Trade and Industry Singapore (2016). Economic Survey of Singapore 2015.
[14] In 2015 electronics was the largest manufacturing industry, contributing almost twice the value of biomedical manufacturing, which was the second most important manufacturing cluster. Williams (2016). Singapore's manufacturing output falls 5.2% in 2015, first yearly contraction since 2009. *The Straits Times.*
[15] Ministry of Trade and Industry Singapore (2016). Economic Survey of Singapore 2015.

30 medtech companies with R&D bases in Singapore,[16] 50 regional headquarters, more than 60 large medtech companies[17] overall, and in excess of 220 medtech start-ups and SMEs.[18]

FIGURE 6 – SINGAPORE: ESTIMATES OF NUMBER OF BIOMEDICAL SCIENCE COMPANIES WITH R&D AND MANUFACTURING IN BIOPOLIS, 2005–2013



Source: These are estimates based on reports from a number of sources, including Yeoh (2007), Vinnova (2008) and the Belgian Foreign Trade Agency (2014). Estimates after 2013 did not appear to be widely available.

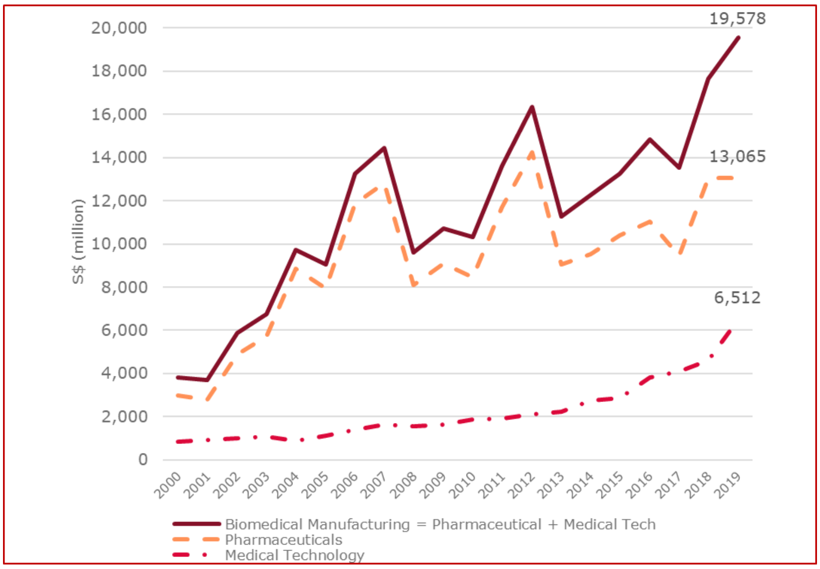
In a 2019 assessment[19] two former civil servants and a Singapore government adviser regarded the biomedical cluster as a case study of a “not-so-successful industrial cluster” with low growth, in comparison with the Jurong Island petrochemical cluster; however, most assessments, including official statistics, contradict this viewpoint.

Strategy Focus on Value Add

As of 2019, in Singapore the biomedical manufacturing sector represented 20% of total manufacturing value added (S$19.57bn, or £11.14bn), equivalent to 4% of Singapore’s GDP. From 2000 to 2019 biomedical manufacturing was the fastest-growing manufacturing sector, with a compound annual growth rate (CAGR) of 9% (compared to the 5% average growth rate of the whole Singapore manufacturing sector). Within this sub-sector the medical technology manufacturing segment experienced a 12% CAGR in added value during the same period.

[16] A*STAR (2020). Medical Technology. *A*STAR*.
[17] SGInnovate (2020). Snapshot of Singapore’s Growing MedTech Industry in 2020. *SGInnovate.*
[18] EDB Singapore (2020). Medical Technology. *EDB Singapore.*
[19] Yeo, G. et al. (2019). Learning and catch-up in Singapore: Lessons for Developing Countries. In Oqubay & Ohno (eds). *How Nations Learn: Technological Learning, Industrial Policy and Catch Up.*

FIGURE 7 – SINGAPORE: VALUE ADDED IN BIOMEDICAL MANUFACTURING, 2000–2019



Source: Own elaboration based on Singapore's EDB Department of Statistics. Department of Statistics Singapore (2020). Singstat.

Did the focus of the Singapore government on value add contribute to the success of the biomedical strategy? While the Singaporean government set five-yearly targets for manufacturing output, in its activities it focused broadly on capturing the whole value chain. In the four decades prior to the biomedical science strategy, Singapore achieved average annual GDP growth of 8.4%, focusing on manufacturing and productivity improvements.[20] Through Tuas Biomedical Park and Biopolis, Singapore aimed to capture the wider biomedical science value chain, as part of an attempt to sustain manufacturing activities, which contributed 25% to the country's GDP.[20]

The early target for the biomedical sciences industry was S$12 billion in manufacturing output by 2005.[20] There was strong growth in the early years, and the target was met a year earlier than expected,[21] reaching S$18 billion in 2005[22] and growing to S$23 billion in 2006, thereby supporting 10,000 jobs.[23] In contrast to much of the cluster literature, the most significant growth in Singapore's biomedical cluster was seen in the early years, perhaps as a result of its strong existing manufacturing base. In 2001 alone S$845 million worth of fixed asset investments was committed through 19 new projects, with multinationals such as Novartis, Eli Lilly, GlaxoSmithKline, Baxter, and Merck Sharp & Dohme.[20]

Later targets aimed for S$25 billion in manufacturing output and 15,000 jobs in the industry by 2015. [23] Despite a manufacturing slump in 2015, biomedical manufacturing had reached S$28 billion in manufacturing output and just under 19,000 jobs.[24] From this point onwards, further targets could not be identified, although it continued steadily but with lower growth, reaching just over 24,000 jobs and S$36 billion total output in 2019.[24]

While value add targets to increase manufacturing output and jobs were met, the same cannot be said for targets set around R&D funding as a proportion of GDP. The government's investment in biomedical

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[20] Lim & Gregory (2004). Singapore's biomedical science sector development strategy: Is it sustainable? *Journal of Commercial Biotechnology*.
[21] Gin (2005). Singapore: The Biopolis of Asia. *Asia Biotech.*
[22] Rai (2006). Overview of the BMS Industry. *APBN.*
[23] Yoh (2008). Singapore's biomedical sciences landscape. *Journal of Commercial Biotechnology*.
[24] Ministry of Trade and Industry Singapore (2016). Economic Survey of Singapore 2015.

sciences has been part of its overall commitment to achieving a gross expenditure on R&D (GERD) of 3% of GDP by 2010.[25] It did not achieve this, peaking at 2.6% GDP in 2008 and dropping to 1.9% of GDP by 2010, a level around which it has fluctuated ever since,[26] failing to meet subsequent higher targets of 3.5% by 2015.[25]

The overall strategy initially succeeded in pulling in additional private funding. In 2000 the ratio of public to private money invested in R&D was 1:1.6, while by 2008 it was 1:2.5,[25] although this subsequently fell to between 1:1.4 and 1:1.6 for the following decade. However, looking at biomedical research alone, the public-to-private R&D investment ratio peaked at 1:0.96 in 2006 and averaged at 1:0.52 between 2000 and 2018.[27]

Start-ups and Innovation

Some argue that, while Singapore has been very successful in attracting manufacturing, it has been less successful in innovating;[28] they claim that by 2016 only a few biopharmaceutical spin-off companies had been launched, and only a couple of novel diagnostics, discovered and developed at Biopolis, had reached the market. However, more than eighty local Singaporean biotech start-ups were incorporated between 2010 and 2018.[29] Singapore is seen as a venture capital (VC) "hotspot", with the highest ratio of VC to GDP and a ranking of eighth out of 131 countries on the Global Innovation Index, the highest in the East Asian region.[30] The World Economic Forum ranks Singapore slightly lower on innovation capability, in fourteenth place.[31]

In the biomedical start-up ecosystem in Singapore today, few companies reach the advanced stages of funding (Series A onwards), but the numbers are broadly in line with the high failure rates at each stage in the start-up funding sequence in other countries.[32]

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[25] Poh (2010). Singapore: Betting on Biomedical Sciences. *Issues in Science and Technology.*
[26] OECD (2020). Gross domestic spending on R&D. *OECDdata.*
[27] Own analysis, based on SingStat data of M081331, Research And Development Expenditure By Area Of Research, Annual. Accessed July 2020.
[28] Muller, J-C (2016). *Singapore Biopolis Fifteen years Later,* Biopharmaceutical News Week Special Edition.
[29] Tan (2019). Biopolis to expand as part of moves to better support biotech start-ups. *The Straits Times.*
[30] WIPO (2020). Global Innovation Index 2020.
[31] WEF (2018). Global Competitiveness Report 2018.
[32] Quinero (2017). Dissecting startup failure rates by stage. *Medium*.

TABLE 3 – START-UP ECOSYSTEM IN SINGAPORE

	Total	Pre-seed	Seed	Pre-series A	Series A	Series B	Series C	Series D Onwards
Total All Areas	3,385	2,944	230	46	79	47	20	19
Biotech	75		6	1	3			1
Pharmaceutical	35		2					1
Pharmaceutical and biotech	100	86	9	1	3			1
Medtech	119	92	13	4	5	4	1	
All biomedical	264	208	30	6	8	8	2	2
Approx mean value, [33] in USD			*$1.5m*		*$6m*	*$9m*	*$14m*	*$16–$30m*

Note: All biomedical includes: medtech, biotech, pharmaceutical, health care, health-care services, complementary health products.
Source: 2020 data, elaboration based on StartupSG. StartupSG (2020). Startups. *Enterprise Singapore.*

Box 3: Innovations from Biopolis

In collaboration with Roche, A*STAR scientists developed a severe acute respiratory syndrome (SARS) detection kit. Another team, in collaboration with Cytos Biotechnology, later Kuros Biosciences Ltd, made substantial progress towards a made-in-Singapore H1N1 flu vaccine. The same is true of a novel experimental dengue vaccine, in development with the Novartis Institute of Tropical Diseases. In July 2015 A*STAR announced the start of a Phase 1 study with ETC-159, a novel cancer drug, jointly developed by Duke-NUS Medical School and A*Star, the first publicly funded drug candidate discovered and developed in Singapore. The trials are expected to be completed by 2023 at the latest.[34]

Another example is SingVax, the first homegrown vaccine company in Singapore. SingVax was founded as a vaccine development company focused on developing vaccines for infectious diseases prevalent in the Asia-Pacific region. SingVax's product candidates included an enterovirus 71 (EV71) vaccine for the prevention of hand, foot and mouth disease in children, a Japanese encephalitis vaccine and a chikungunya virus vaccine. SingVax, headquartered in Singapore, received investments from Bio*One Capital, the venture capital arm of the Singapore government.

In terms of R&D employment, Singapore employs five times more biomedical researchers per capita than the US. Singapore, with a population of around 5.6 million and approximately 7,150 biomedical researchers in 2018 (Table 1), has an estimated 128 biomedical researchers per 100,000 inhabitants. The US, with a 2017 population of 328.2 million and approximately 80,000 biomedical researchers, had only 24 researchers per 100,000 inhabitants.

There is a strong indication in the Singaporean case study that early government investment has led to larger FDI at later stages by multinational companies, with an example detailed in Box 4 (below).

[33] Based on Investopedia, and investment amounts are based on statistical studies in the US between 1994 and 2000. In Davila, Foster and Gupta (2003). Venture capital financing and the growth of start-up firms, *Journal of Business Venturing* , Vol. 18, Issue 6, pp. 689–708.
[34] A*Star (2020). Made-In-Singapore Cancer Drug Etc-159 Advances Further In Clinical Trials.

Box 4: Early government investment leading to multinational investment and commercial success

In 2003 the Singaporean government set up A-Bio, a biologics contract manufacturer funded by Bio*One Capital investments to provide small-scale manufacturing services. In October 2003 A-Bio made a strategic move to acquire the 200-litre Good Manufacturing Practice (GMP) facility from the BMTC. Within a few years of operation of the 200L GMP facility, A-Bio had already established a strong track record. Its customers included GlaxoSmithKline Biologicals and Novo Nordisk A/S, while its strategic partners included Artisan Pharma, Inc.

In 2004 A-Bio announced that the company had entered into a process development and clinical supply service agreement with GlaxoSmithKline's vaccine division. Under the contract, A-Bio worked closely with GSK Bio to develop and produce clinical lots for one of its many promising vaccine products at A-Bio's GMP facility in Singapore. In 2005 A-Bio secured its second process development and clinical supply service agreement with GSK Bio. Securing this project allowed A-Bio to expand its cell culture manufacturing capacity to meet customer demand by investing S$9 million in order to add a 500L stirred tank bioreactor to its existing 200L capacity.

The result of these collaborations was an investment of S$600 million by GSK in an 85,000 sqm biotech vaccine manufacturing facility in Tuas Biomedical Park that employs 400 skilled workers and which opened in June 2009.[35]

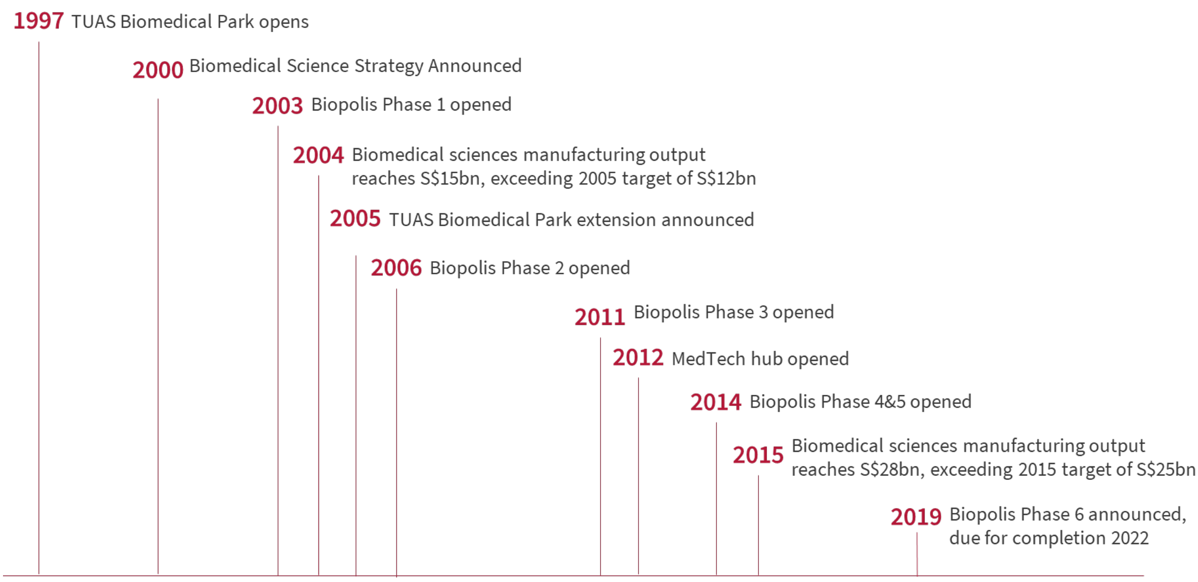
[35] GSK (2009). GlaxosmithKline Opens $600million Vaccine Plant. *Industry Watch.*

BIOPOLIS: SINGAPORE'S BIOMEDICAL SCIENCES HUB INITIATIVE

Singapore's biomedical science approach, launched in 2000, is analysed here along the following five-year stages, which align with five-year government funding cycles:

- **Pre-2000:** Before Biopolis
- **2000–2005:** The Creation of Biopolis – Sowing the Seeds
- **2006–2010:** Attraction Phase – Bringing in Scientists and Multinational Corporations
- **2010–2015:** The Consolidation on Biopolis – Industrial Alignment
- **2016–2020:** Reaping the Rewards – Continued Growth

FIGURE 8 – SINGAPORE'S BIOMEDICAL SCIENCES HUB KEY MILESTONES



Pre-2000: Before Biopolis[36]

In 1986, in the depths of a recession, the government of Singapore recognised that their niche as an offshore production centre for the developed world would be eroded by increased competition from developing nations. Noting the internal limitations of Singapore, including the lack of a large domestic market, continued dependence on the international trading system and the absence of natural resources, they moved to become an "international business centre". This involved a plan to attract companies to establish operational or regional headquarters in Singapore, which are responsible for subsidiaries throughout the Asian region and which conduct product development work. Following this, they argued, it would become worthwhile for multinational corporations to establish a manufacturing plant in Singapore to produce goods to export.

[36] Unless otherwise stated, this section is based on: Singapore Ministry of Trade and Industry (1986). The Singapore Economy: new directions: report of the Economic Committee.

The biomedical sciences strategy was developed in 2000 with the aim of diversifying the economy beyond IT and electronics manufacturing,[37] following a financial crisis in 1997–8.[38] While in the 1990s there was an important presence of large foreign pharmaceutical companies in Singapore, their presence consisted primarily of manufacturing sites, with negligible presence of biotechnology firms and no production of next-generation biopharmaceutical drug products.[39]

At the time of the conception and implementation of Singapore's biomedical strategy, the country already had an important pharmaceutical manufacturing presence. Furthermore, Tuas Biomedical Park opened in 1997, providing 370 ha of prepared land with ready-made infrastructure for pharmaceutical and biologics manufacturing, including access to roads, drainage power systems, power, water supply and telecommunication lines.

Research and development in basic biomedical science in Singapore had previously been supported through the creation of the Institute of Molecular and Cell Biology in 1987. Applied manufacturing research in this sector began in 1995 with the establishment of the Bioprocessing Technology Institute, and the Centre for Drug Evaluation was set up in 1998. The 2000 biomedical strategy would see Singapore create more than a dozen of these organisations, and it included investment in the development of human, intellectual and industrial capital, in addition to a bioethical framework.

2000–2005: The Creation of Biopolis – Sowing the Seeds

The first stage of Singapore's biomedical sciences hub initiative focused on three main objectives:

1. Creation of physical infrastructure to conduct research in Biopolis;
2. Global headhunting of experts to lead the research institutions;
3. Partnership with (and attraction of) foreign multinational companies.

Initially, US$1 billion was allocated to building Biopolis, as well as several new life science research institutes, and to providing co-funding for new R&D projects by global pharmaceutical firms.[40] Designed by Zaha Hadid and officially launched in 2003, Biopolis was designed to foster cross-disciplinary collaboration and bridge the gap between academic and industrial research. Biopolis was designed to bring together key Singaporean biomedical research institutes, global and local biotechnology and pharmaceutical companies, and national governance bodies.

Creating a knowledge sector in Biopolis was a strategic priority, particularly in the early stages. Headhunting activities were undertaken, as described further in the "People" section on page 25. The Economic Development Board (EDB) helped the Bioprocess Technology Institute (BTI) to start a local training programme, and an overseas programme was also created to train a pool of 350 highly skilled Singaporean biotechnologists.[41]

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[37] Sandstrom A. (2009). Singapore, Aiming to create the Biopolis of Asia, *VINNOVA.*
[38] Lim & Wei (2010). A Case Study of the Pharmaceutical Industry in Singapore. *IISD.*
[39] Wong Poh-Kam (2006). Toward an ecosystem for innovation in a newly industrialized economy, Singapore and the life sciences. *Industry and Higher Education*, August 2006. Beh (2011). Making medicine, saving lives. In Chan, Chin Bock (2011). *Heart Work 2: EDB & partners: new frontiers for the Singapore economy.* Singapore: Straits Time Press: Singapore Economic Development Board.
[40] Wong et al. (2010). Industrial Cluster Development and Innovation in Singapore. *From Agglomeration to Innovation,* pp. 50–116.
[41] Beh (2011). Making medicine, saving lives. In Chan, Chin Bock (2011). *Heart Work 2: EDB & partners: new frontiers for the Singapore economy.* Singapore: Straits Time Press: Singapore Economic Development Board.

By 2000 Singapore had a good reputation for chemical pharmaceuticals manufacturing but no biologics manufacturing presence. The EDB started approaching multinational corporations, and in 2004 Novartis established in Biopolis the Novartis Institute for Tropical Diseases (NITD), a small molecule drug discovery research institute dedicated to finding new medicines to treat neglected infectious diseases such as dengue haemorrhagic fever and tuberculosis.

To promote domestic capability, the EDB also planned to create the first homegrown drug discovery company. Under Bio*One Capital, the S$1 billion Biomedical Science Investment Fund was set aside to invest in Singapore-based joint ventures, overseas biotechnology companies and local start-ups over a period of five years.[42] For these purposes, a joint venture was established with the US-based biotechnology firm Chiron. This joint venture led to the creation of S*BIO, which developed an oncology programme focused on the development of histone deacetylase (HDAC) inhibitors and delivered its first candidate for clinical development in 2006.

In 2003 the Singaporean government set up A-Bio, conceived as a biologics contract manufacturer to provide a range of manufacturing solutions for mammalian cell culture systems, including process development, optimisation, manufacturing scale-up, GMP production, quality control and regulatory compliance. Within a few years of operation, A-Bio had established a strong track record, and its customers included GlaxoSmithKline Biologicals and Novo Nordisk A/S, while its strategic partners included Artisan Pharma, Inc.

As well as attracting leading multinational corporations, the government of Singapore also provided venture capital. In 2005 the EDB partnered with Lonza, a Swiss chemicals and biotechnology multinational, to start the construction of its first biologics manufacturing facility in Singapore in 2006, through a US$250 million joint venture with Bio*One Capital. This was Lonza's first large-scale mammalian cell culture plant located outside the US.[43] Genentech, a leading biotechnology company, entered into a supply agreement with Lonza to manufacture its products, and it later acquired the facility and built a second biologics plant in Singapore. Lonza would partner again with Bio*One Capital in order to build a second biologics plant. This sequence of investments supported Singapore's reputation as a viable site for biologics manufacturing in Asia. Thus, the seeds of industrial R&D and biologics manufacturing presence were planted.

By 2005 there were around 1,500 scientists working in Biopolis, and some companies that had already arrived included GlaxoSmithKline, Novartis, ES Cell International, Johns Hopkins, Waseda-Olympus, Vanda Pharmaceuticals, Paradigm Therapeutics and Proligo Singapore. Other organisations that had moved in included the British High Commission's Science & Technology Office, Swiss House and the Singapore Health Sciences Authority.[44] In Tuas Biomedical Park, Vision, Lonza, Merck Sharpe & Dohme, Novartis, Pfizer, Wyeth Pharmaceuticals and Wyeth Nutritionals had already arrived. Outside TBP and Biopolis, other multinational biomedical companies operating in Singapore included GlaxoSmithKline, Sanofi-Aventis, Schering-Plough, Baxter, Becton Dickinson, Kaneka, among others. In 2004 Singapore's

[42] Lim & Gregory (2004). Singapore's biomedical science sector development strategy: Is it sustainable? *Journal of Commercial Biotechnology*.
[43] Wong N. & Yap M. (2007). The future of biomanufacturing in Singapore, Special Issue: Singapore Biotech Crossroads, *Biotechnology Journal*, 2007, 2, 1327–1329
[44] Gin (2005). Singapore: The Biopolis of Asia. *Asia Biotech.*

biomedical sciences manufacturing output reached S$15 billion, exceeding its 2005 target of S$12 billion a year earlier than expected.[45]

2006–2010: Attraction Phase – Bringing in Scientists and Multinational Corporations

The second stage was arguably the most rapid stage of expansion for Biopolis. This stage of the biomedical sciences hub initiative focused on strengthening biomedical science capabilities to scale up scientific discoveries, with a focus on translation. In 2005 the national Translational and Clinical Research (TCR) programme was launched, jointly funded by the Ministry of Health, A*Star and the National Research Foundation. This was supported by a substantial increase in public R&D budget allocation (Figure 10)[46] that funded, among others, the Academic Research Council and the establishment of Research Centres of Excellence, five based in the two largest universities in the country, the National University of Singapore and the Nanyang Technological University.[47]

The TCR programme followed three strategic lines. The first focused on human resources to support the TCR programme itself. A number of highly qualified clinician scientists from abroad were recruited through the Singapore Translational Research Investigator Award, which was open to international competition. To develop local human resources, the Clinician Scientist Award focused on scientists from Singapore. The second strategic line of the TCR programme focused on conducting research on relevant diseases for Singapore and the Asian region, integrating basic, translational and clinical scientists. The last strategic line of the TCR programme involved the creation of two academic medical centres bringing together large hospitals and their companion medical schools (National University Hospital, Duke-NUS and Singapore General Hospital). This initiative included the creation of an investigational medicine unit in each academic medical centre, the creation of a national imaging centre dedicated to clinical research, and the creation of a national clinical trials network.

During this stage of Singapore's biomedical sciences hub initiative, other multinational corporations moved into the country, and many of the new Biopolis facilities were marketed to private companies.[48] This was highly successful; for example, MSD expanded their footprint into R&D in Singapore by opening a Translational Medicine Research Centre (TMRC) at Biopolis.[49] During this period, GlaxoSmithKline invested US$300 million in a new vaccine manufacturing plant, Abbott Laboratories invested US$280 million in a new infant nutritional powder plant, Eli Lilly expanded drug discovery research activities by US$150 million, Genetech invested £140 million in a new plant for biomedical manufacturing, and several other companies made similar investments in new manufacturing plants in the country,[50] many in Tuas Biomedical Park.

By 2010 Singapore had become home to more than 4,300 international researchers,[51] and GlaxoSmithKline, Novartis, Pfizer, Merck, Aventis, Eli Lilly, Wyeth, Roche and Schering-Plough had

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[45] Gin (2005). Singapore: The Biopolis of Asia. *Asia Biotech.*

[46] Muller, J-C (2020). *Singapore Biopolis Fifteen years Later*, Biopharmaceutical News Week Special Edition.

[47] Poh L.C. (2016). Chapter 10 From Research to Innovation to Enterprise: The Case of Singapore. In *Global Innovation Index 2016, Winning the Global Innovation,* Cornell University, INSEAD, WIPO.

[48] Poh L.C. (2016). Chapter 10 From Research to Innovation to Enterprise: The Case of Singapore. In *Global Innovation Index 2016, Winning the Global Innovation,* Cornell University, INSEAD, WIPO.

[49] MDS (2020). MSD in Singapore. *DPS Education.*

[50] Sandström (2009). Singapore – Aiming to create the Biopolis of Asia. VINNOVA – Verket för Innovationssystem/Swedish Governmental Agency for Innovation Systems.

[51] Beh (2011). Making medicine, saving lives. In Chan, Chin Bock (2011). *Heart Work 2: EDB & partners: new frontiers for the Singapore economy.* Singapore: Straits Time Press: Singapore Economic Development Board.

established operations in Singapore.[52] The total researcher population in Singapore had grown from 2,150 in 2002 to over 5,400 in 2011, including around 100 clinician scientists, with almost half located at Biopolis.[53]

2011–2015: The Consolidation of Biopolis – Industrial Alignment

In 2010 the decision was made to "industrially align" the biology research institutes of Biopolis. This resulted in an increased turnover of researchers within these institutes and a two-year period of uncertainty regarding budgets, as well as increased grant applications and pursuit of industry collaboration.[54]

The MedTech Hub, a new innovative industrial park in a single building, was developed by the JTC Corporation during 2012–13 in order to host medical technology manufacturing.[55,56] The medical technology sector consists of medical devices and instruments, and it was a new direction added to the biomedical strategy in 2013 alongside personal care, food and nutrition.[57] Spanning nine stories and 38,900m^2, the spaces are targeted at medical device manufacturers.

There were also innovation successes. In July 2015 A*STAR announced the start of a Phase 1 study of ETC-159, a novel cancer drug, the first publicly funded drug candidate discovered and developed in Singapore. Providing further support within an aspect of the biomedical strategy, in 2014 the Singaporean government launched the Diagnostics Development (DxD) Hub, led by A*Star, one of four innovation clusters funded under Singapore's S$200 million Innovation Cluster Programme.

The attractive effect of the Singaporean biomedical cluster led to new activities from Roche, Novartis, GSK, Chugai, Procter & Gamble, ArKray, Flugidim, Nestlé, Danone Nutrica Reseach and L'Oréal, among others. Having already established their regional headquarters in Singapore, Procter & Gamble's Singapore Innovation Centre opened in 2014, representing an investment of S$250 million. In 2016 GSK designated Singapore as its Asia headquarters.[58]

In 2013, at the tenth anniversary of Biopolis, the cluster hosted more than 40 private companies,[57] and by 2016 Biopolis had hosted 53 companies and 5,600 employees.[59] Singapore had attracted more than fifty manufacturing plants (nine of them producing biomedical products), established around fifty new research facilities and located more than thirty regional headquarters of multinational companies in the field.

2016–2020: Reaping the Rewards – Continued Growth

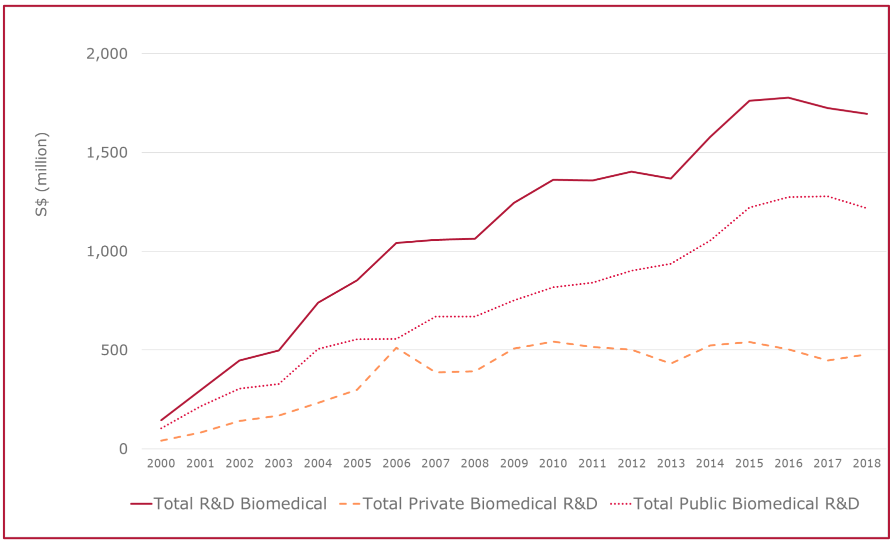
From 2015 onwards, targets for growth in biomedical sciences could not be identified, and public R&D in biomedical sciences levelled off, indicating a less active role for the Singaporean government in driving the biomedical cluster, perhaps an indication of the cluster's maturity. Nonetheless, the biomedical

[52] Lim & Wei (2010). A Case Study of the Pharmaceutical Industry in Singapore. *International Institute for Sustainable Development.*
[53] Biospace (2013). Singapore's Biopolis: A Success Story.
[54] Fischer (2018). A Tale of Two Genome Institutes: Qualitative Networks, Charismatic Voice, and R&D Strategies—Juxtaposing GIS Biopolis and BGI. *Science, Technology, and Society, 23*(2).
[55] JTC Corporation (2011). Annual Report 2011.
[56] Kiang (2012). Mr Lim Hng Kiang at the Launch of the MedTech Hub, 12 April 2012. *Ministry of Trade and Industry, Singapore.*
[57] Biospace (2013). Singapore's Biopolis: A Success Story.
[58] PharmaLogistics (2017). Singapore Transforms into Pharma and Medtech Hub. *Pharma Logistics IQ.*
[59] Muller (2017). Singapore Biopolis Fifteen Years later. *BtoBio Innovation*.

sector continued to grow. During the last five years, there has been continued growth in the biomedical manufacturing industry, from S$28 billion in manufacturing output and just under 19,000 jobs[60] in 2015 to S$36 billion in manufacturing output and 24,000 jobs in 2019.[61]

Over the last five years R&D investment in the biomedical industry levelled off (Figure 9). In 2016 the Singaporean government's R&D funding plan allocated S$4 billion to the domain of health and biomedical sciences, representing 21% of the S$19 billion that Singapore planned to invest in public R&D during this period. In 2018 the guaranteed funding for core research activities and overheads of A*Star scientists was cut by 20%. In 2019 further cuts in fixed funds were announced, unsettling the biomedical research community, with some even considering leaving for overseas institutes.[62]

FIGURE 9 – SINGAPORE: R&D INVESTMENT IN BIOMEDICAL INDUSTRY BY SOURCE, 2000–2018



Source: own elaboration, based on Singapore's EDB Department of Statistics. Department of Statistics Singapore (2020). Singstat. Retrieved July 2020.

Singapore's medtech industry grew similarly, from 100 Singaporean medtech companies in 2014 to more than 250 by 2018.[63] To further support applied medtech, the Singapore Health Technologies Consortium (HealthTEC) was launched in 2019 by Singapore's National Research Foundation.[64] In 2019 a new medtech co-working hub named Catalyst was opened[65] in the city centre, close to hospitals, to complement the existing manufacturing-targeted space and target health-care product and service development, particularly at start-up levels.

[60] Ministry of Trade and Industry Singapore (2016). Economic Survey of Singapore 2015.
[61] Ministry of Trade and Industry Singapore (2019). Economic Survey of Singapore 2019, Statistical Annexes.
[62] Yeo, G. et al. (2019). Learning and catch-up in Singapore: Lessons for Developing Countries. In Oqubay & Ohno (eds). *How Nations Learn: Technological Learning, Industrial Policy and Catch Up.*
[63] IndSights Research (2020). The MedTech scene in Singapore. *IndSights Research.*
[64] SGInnovate (2020). Snapshot of Singapore's Growing MedTech Industry 2020. *SGInnovate.*
[65] Chong (2019). MedTech Hub opens with support from Singapore's healthcare clusters. *Business Times.*

TABLE 4 – BIOMEDICAL COMPANIES IN SINGAPORE

Year Est.	Biomedical Company	Product Family	Treatment Family	Project Site Activity
2003	A-Bio (today part of Luye Pharma)	Biomanufacturing contracting		Manufacturing, R&D
2004	Novartis	Pharmaceuticals		Manufacturing
2004	Pfizer	Pharmaceuticals		Manufacturing
2005	Biosensors International	Medical devices	Cardiology and critical care	Manufacturing, R&D
2005	Veredus Laboratories	Medical devices	Influenza viruses	R&D
2006	Lonza Biologics Singapore	Biomanufacturing contracting		Manufacturing, R&D
2007	Affymetrix Inc.	Diagnostics	Oncology	Manufacturing
2007	Schering-Plough	Monoclonal antibody	Hepatitis C, Crohn's disease, rheumatoid arthritis	Manufacturing
2009	Roche	Monoclonal antibody	Age-related vision loss macular degeneration	Manufacturing
2009	Genentech Roche Singapore Biologics Plant (formerly Lonza Biologics)	Monoclonal antibody, other biologics	Oncology, Inflammation, virology, metabolic disease, central nervous system	Manufacturing
2011	GSK Biologics, JTC Corp	Vaccines	Infectious diseases such as meningitis, typhoid, influenza, bacterial pneumonia	Manufacturing
2012	Lonza Bioscience Singapore Ltd	Biomanufacturing	Mammalian and bacterial manufacturing	Manufacturing
2012	Novartis Biomanufacturing Plant	Monoclonal antibody	Oncology, asthma, arthritis	Manufacturing
2012	Chugai Pharmabody Research	Antibody		R&D
2014	Amgen	Monoclonal antibody	Osteoporosis and oncology	Manufacturing
2014	Amgen	Monoclonal antibody	Rheumatoid arthritis, psoriasis, spinal back pain, Crohn's disease,	Manufacturing
2014	Shire	Antihemophilic and coagulants	Hematological diseases	Manufacturing
2014	Prime Biologics	Haematology product manufacturing		Manufacturing, R&D
2014	Privi Medical	Health products manufacturer		Manufacturing
2015	MSD	Data-assisted health care		R&D
2016	Esco Aster	Biomanufacturing and medical technology		Manufacturing, R&D
2016	Lucence	Genomic medicine, diagnosis	Oncology	R&D, Manufacturing
2017	AbbVie			Manufacturing, R&D
2017	Kronikare	AI-assisted health care	Wound diagnosis	Manufacturing
2018	Amgen	Monoclonal antibody manufacturing support	Rheumatoid arthritis, psoriasis, spinal back pain, Crohn's disease	Manufacturing
2019	MSD		Oncology and immunology	Manufacturing
2019	PerkinElmer	Instrument manufacturing		Manufacturing

In 2020, despite the COVID-19 pandemic, Singapore displayed overall manufacturing growth that was driven in large part by biomedical manufacturing.[66] Biomedical manufacturing expanded by 27% in the first half of the year, while medical technology declined by 1.4%.

Indeed, the domestic industry was part of the response. Working closely with the National Centre for Infectious Diseases (NCID), scientists at Duke-NUS Medical School successfully cultured the COVID-19 virus just one week after it was first detected in the country in January 2020.[67] In the same month the Singapore National Public Health Laboratory, together with the public hospitals, developed and ramped up a diagnostic test for the virus that allowed the Ministry of Health to carry out more than 21,000 tests from the end of January to 17 March 2020, while also supporting testing in China.[67] In 2020 more than 150 provisional authorisations for COVID-19 tests were given by the Singaporean Health Sciences Authority.[68]

TABLE 5 – A SNAPSHOT OF ACTIONS TAKEN AROUND COVID-19 RESPONSE BY SINGAPOREAN COMPANIES IN 2020[67,69,70,71,72]

Investor/Company (Country of Operations)	**Description**
A*Star (SG), Tan Tock Seng Hospital (SG) and MiRXES (SG)	Developed COVID-19 testing kit, Fortitude 2.0, deployed in hospitals by February.
Veredus (SG)	Developed COVID-19 testing kit, given provisional licence in March.
Biolidics (SG)	Developed COVID-19 antibody/antigen testing kits, given provisional licence in March.
Acumen Research Laboratories (SG)	Developed COVID-19 testing kit, given provisional licence by April.
Duke-NUS (SG)	Developed cPass to detect COVID-19 neutralising antibodies.
Gilead Sciences (SG)	In March announced it was widening clinical trials in Singapore for its anti-viral drug, remdesivir, for the treatment of COVID-19.
Arcturus Therapeutics (SG) with Duke-NUS Medical School (SG)	Developing vaccines for COVID-19, including clinical trials in Singapore.
Esco Aster (SG) and Vivaldi Biosciences (US)	Working on the manufacture of a COVID-19 chimeric vaccine.
Moderna (US), in cooperation with Lonza (SG)	Singapore site set to manufacture vaccine developed in the US by 2021.
Biofourmis (SG)	Customised its Biovitals Sentinel biosensor platform to detect symptoms of deterioration in COVID-19 patients.

The government looks set to continue support for the biomedical industry into the immediate future. In late 2019 the government announced that the sixth phase of Biopolis would be built by mid-2022, adding 35,000m^2 of space for biomedical sciences research and 6,000m^2 for office and retail use, particularly to support biotech start-ups.[73]

[66] Ministry of Trade and Industry Singapore (2020). Performance and Outlook of the Manufacturing Sector in 2020.
[67] Seet (2020). Commentary: Why Singapore is better prepared to handle COVID-19 than SARS. *CNA International.*
[68] HSA (2020). HSA Expedites Approval of COVID-19 Diagnostic Tests in Singapore via Provisional Authorisation. *Health Sciences Authority, Government of Singapore.*
[69] Chong (2020). Key biotech players in Singapore join hands to beef up COVID-19 test capacity. *The Straits Times.*
[70] Koh (2020). Veredus Laboratories' VereCoV detection kit obtains provisional approval for IVD use. *Mobihealth News.*
[71] DukeNUS (2020). Arcturus Therapeutics-Duke-NUS clinical trials for COVID-19 vaccine candidate approved to proceed. *DukeNUS.*
[72] IndSights Research (2020). The MedTech scene in Singapore. *IndSights Research.*
[73] Tan (2019). Biopolis to expand as part of moves to better support biotech start-ups. *The Straits Times.*

SUPPORTING POLICIES FOR SINGAPORE'S BIOMEDICAL CLUSTER

This case study will evaluate the supporting policies used to develop Singapore's biomedical industry using success factors usually seen in innovation clusters, developed by the Brookings Institution[74] and recently employed by the Royal Society in their study of innovation clusters in the UK, US, Sweden, Taiwan and Israel. This framework, while sharing many commonalities with the broader cluster literature,[75] is used to highlight activities within distinct arms of the overall strategy to allow for evaluation.

Box 5: Success factors usually seen in innovation clusters[76,74]

- **Access to funding** – for start-ups, infrastructure, research, etc.
- **People** – strong leadership, highly qualified researchers and a skilled workforce
- **Infrastructure provision** – including airports, highways, housing and building stock
- **A core competency** – such as an area of research strength
- **A supportive regulatory environment**
- **Sophisticated demand** – to take on innovative products and services, ideally within the cluster
- **Business capabilities** – particularly business skills within start-ups
- **Culture** – sharing between business and research, and a lifestyle to attract talent

Added because of its significant importance in this context is the notion of **co-location of public institutions**, which is considered in its own right as a supporting policy in the Singaporean context.

While the cluster concept is not new, and subject to debate, it is an attractive concept that is often implicitly or explicitly used in government strategies.[77] It is particularly relevant to the creation of Biopolis in the Singaporean context, because of the country's decision to pursue a cluster-based strategy despite its small overall size. While not all the success factors will be present in every innovation cluster, enough must be present to allow a successful cluster to develop.

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[74] Baily & Montalbano (2017). Clusters and Innovation Districts: Lessons from the United States Experience. *The Brookings Institution.*

[75] While other frameworks were considered, such as European Commission Smart Specialisation Strategies, Porter's (1998) identification of cluster benefits, and the OECD's categories of instruments (OECD, 2007, p. 92), this framework proved most useful for our aim of distinguishing between arms of strategy used in this particular cluster case study. Most frameworks share core themes, such as a skilled labour force, access to finance for spin-offs, and so on, which are well represented in the Brookings list above. However, other frameworks either provided insufficient granularity, were designed more for description than evaluation or were focused on identification and classification of types of cluster, leading to our selection of this framework for the purposes of this case study.

[76] The Royal Society (2020). Research and Innovation Clusters.

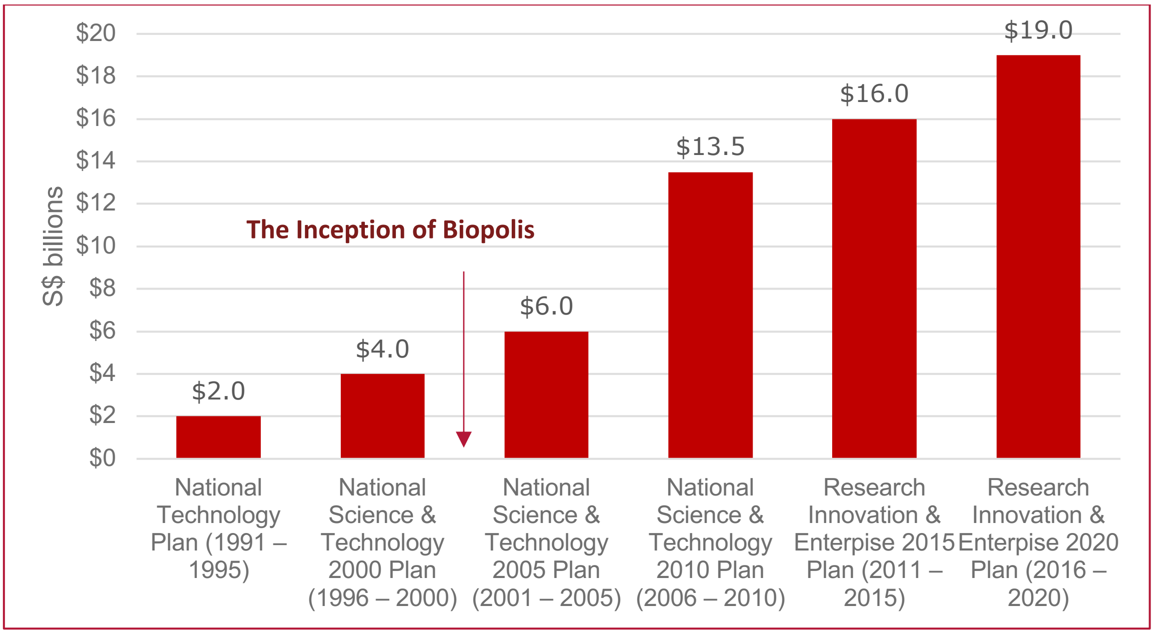
[77] OECD (2007). Competitive Regional Clusters: National Policy Approaches. *OECD.*

Access to Funding

To catalyse this biomedical cluster, the Singaporean government invested significantly in R&D, including through publicly funded research institutes, venture capital funds and continued use of tax incentives to attract international companies and FDI.

The government remains the main investor in biomedical R&D investment, at the level of S$1.2 billion in 2018. From 2000 to 2018 the Singapore government invested an estimated S$14.16 billion in biomedical R&D, at an average level of S$746 million/year.[78]

FIGURE 10 SINGAPORE'S PUBLIC R&D BUDGET BY FIVE YEARS PLANS



Source: Adapted from Poh L.C. (2016, Figure 1). From Research to Innovation to Enterprise: The Case of Singapore.

Since 1985 the Singapore government has nurtured the venture capital industry in the country.[79] The EDB has played a key role in two ways: direct investments in venture capital; and establishing strategic programmes to promote VC development in Singapore, including tax and non-financial incentives.[80] In 1985 the EDB created its first S$100 million venture capital fund. EDB Investments Ptd Ltd (EDBI) was set up in 1991 as an independent investment equity, wholly owned by the EDB, with the aim of accelerating the growth of enterprises and industry clusters and promoting emerging industries and innovative technologies.[81] Since its inception, EDBI has invested in other venture capital funds and directly in start-up companies, both in Singapore and abroad. In 2001 EDBI managed funds in excess of S$6 billion.[81] In 2001 EDBI created Bio*One Capital, a fully owned subsidiary of EDBI, with the aim of supporting the biomedical sciences initiative. Managing S$1.2 billion in funds, the company invests in drug discovery/development, biologics and cellular therapy, and medical technology companies and start-ups.[82] Today, EDBI has a portfolio of 63 companies distributed between Singapore (25%) and abroad

[78] Source: Analysis of SingStat data, M081331, Research And Development Expenditure By Area Of Research, Annual, accessed July 2020.
[79] Unless otherwise stated, this section is based on: Teik B.K. (2011). Chapter 7 Making Medicine Saving Lives.
[80] The use of tax incentives to attract FDI is discussed further in the Policy Implications section below. See also: Wei & Lei (2020). Venture capital investment in Singapore: market and regulatory overview. *Thompson Reuters Practical Law.*
[81] Wang (2004). The emergence of the Singapore venture capital industry: investment characteristics and value-added activities. In Bartzokas & Mani (eds). *Financial Systems, Corporate Investment in Innovation, and Venture Capital,* pp. 225–251.
[82] Wong et al. (2010). Industrial Cluster Development and Innovation in Singapore. *From Agglomeration to Innovation,* pp. 50–116.

(75%) in a diversified portfolio of technological sectors, including health care (27% of the portfolio), emerging technologies and ICT.

The Singaporean government, from the outset, looked to invest directly in ventures. Enterprise Singapore co-funds Singapore-based start-ups, and since 2014 its investment arm, SEEDS Capital, has co-invested more than S$90 million in more than twenty medtech start-ups.[83] Singapore's EDB set out to create the first homegrown drug discovery company through a joint venture with Chiron, the third-largest company in the sector at the time. With 3,000 employees, Chiron's drug discovery platform was identifying more potential drug targets than its team could process. In 2000 S*BIO was created as a joint venture that would follow up the drug targets in collaboration with Chiron. It developed an oncology programme focused on the development of histone deacetylase (HDAC) inhibitors, and it delivered its first candidate for clinical development in 2006.

There is intense global competition in life sciences, which leads to the increased importance of incentives to attract FDI. Some of the strategies used at the inception of the biomedical strategy are listed in the box below. Today, Singapore's corporate tax rate sits at 17%, compared to an EU average of just over 20% and a UK rate of 19%, while the world average was around 23.8% in 2020, with the US at 27%, Ireland at 12.5%, and Germany and Japan at 30%.[84]

Box 6: Tax incentives for investment in Singapore at the launch of the biomedical strategy

At the time of the launch of Biopolis, the tax and grant incentives schemes included,[85] among other incentives, the following:

- Complete exemption from the 25.5% corporate tax on profits for 5–10 years for new manufacturing and service investments introducing high-tech skills.
- Concessionary tax rate of 13% for up to 10 years for firms engaging in new projects or expanding or upgrading operations in Singapore that result in significant economic spin-offs.
- Exemption of taxable income equal to a specified proportion of new fixed investment for companies engaged in industries such as manufacturing, engineering services, R&D activities and construction.
- Exemption from withholding tax on interest payable to foreign lenders above S$200,000.
- Full or partial exemption of withholding tax on royalties for eligible companies.
- For companies >50% owned by Singaporean citizens or permanent residents, the ability to offset losses incurred from the sale of shares or liquidation of up to 100% of equity invested overseas against their other taxable income; and exemption of corporate tax on qualifying income earned from approved overseas investments and projects for up to 10 years.
- For operational headquarters, a concessionary corporate tax rate of 10%, while global headquarters are eligible for full tax exemption.

[83] Marshall Cavendish Business Information (2020). Riding the MedTech Wave. *singaporemedtech.com.*
[84] KPMG (2020). Corporate Tax Rates Table.
[85] Lim & Wei (2010). A Case Study of the Pharmaceutical Industry in Singapore. *IISD.*

People

As a result of its initial lack of a core competency, at the heart of Singapore's strategy to create a biomedical sector was a comprehensive approach to attracting international expertise while developing domestic capability, with a shift in importance over time, the latter being favoured more in later years as the cluster matured. This included government-sponsored global headhunting of top scientists and A*STAR's ambitious programme of scholarships for training at BSc, PhD and postdoc level in leading universities and laboratories abroad, with a reduction in scholarships for non-Singaporeans in the later stages.[86]

Philip Yeo, Chairman of A*STAR from 2000 to 2007, is credited with much of the development of the Biomedical Science Initiative (BMSI). He set out to bring the world's best scientists to Singapore, based on the assumption that bringing the best researchers in the biomedical field would, in turn, attract the best students, junior researchers and faculty members.

Box 7: Top scientists recruited by the chairman of A*STAR

Professor Sir David Lane, who discovered the p53 tumour suppressor gene, arrived in a two-year role as Executive Director of the Institute for Molecular and Cell Biology (IMCB) and is today Chief Scientist of A*Star.[87]

Edison Liu, former Head of the Division of Clinical Sciences at the National Cancer Institute (NCI) in the US, became the Executive Director of the Genome Institute of Singapore (GIS) from 2001 to 2011.

Yoshiaki Ito, a Japanese cancer researcher who identified *RUNX3* as a tumour suppressor gene associated with stomach cancer, relocated to the IMCB in 2002 – with his entire laboratory staff in tow – after reaching Japan's mandatory university retirement age of 63. Then, in 2008 he joined the newly established Cancer Science Institute of Singapore at the National University of Singapore (CSIS-NUS) as Senior Principal Investigator and Professor of Medical Oncology.

Molecular biologist Alan Colman, formerly with PPL Therapeutics, the Scotland-based pharmaceutical company that cloned Dolly the sheep, received a S$6 million grant to relocate to Singapore and was Chief Scientific Officer of ES Cell International, a public–private-funded biotech company[88] developing human embryonic stem cells for disease therapy from 2002 to 2007. He then served as Executive Director of the Singapore Stem Cell Consortium and a Principal Investigator at the Singapore A*STAR Institute of Medical Biology (2006–2013); he is now Non-Executive Director of VolitionRX Ltd, a firm developing a cancer screening method based on blood sampling, with R&D based in Belgium.

The late Nobel laureate Sydney Brenner, long-time adviser to the Singaporean government (he served as Chairman of Singapore's Scientific Advisory Board from 1987 to 1997), was Chairman of the BMRC. Brenner spent his time between Singapore and the Salk Institute for Biological Studies in San Diego. He was supported by the late Leslie Barnett (also former Cambridge LMB) in setting up Brenner's lab in Singapore.

According to a 2006 interview, the common denominator that helped them decide to go to Singapore was Phillip Yeo, Chairman of A*STAR at the time.

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[86] Fischer (2018). A Tale of Two Genome Institutes: Qualitative Networks, Charismatic Voice, and R&D Strategies—Juxtaposing GIS Biopolis and BGI. *Science, Technology, and Society, 23*(2).
[87] A*Star (2020). Corporate Profile: Professor Sir David Lane. *Agency for Science, Technology and Research.*
[88] Burton J (2005). ES Cell International – In Singapore, a company with ambitious goals leads a "privileged existence". *Scientific American.*

In the second stage (2005–9), one initiative was a focus on developing human resources for the support of a robust translational and clinical research effort. This initiative was kick-started by recruiting a number of highly qualified clinician scientists from abroad through the Singapore Translational Research Investigator Award, which was opened to international competition. In order to develop local human resources, this programme was partnered with the Clinician Scientist Award, which was focused on local scientists.

In the first 10 years the researcher population in Singapore grew from 2,150 in 2002 to over 5,400 in 2011, including around 100 clinician scientists. Almost half are located at Biopolis. In addition, Singapore was supporting the development of human resources by funding young Singaporean scientists whose academic studies were funded through the A*STAR scholarships.

While not all of the senior scientists were retained, this was generally attributed by the researchers to longevity of funding, inconsistency in government expectations and changes to funding approaches between cycles.

In December 2014 the Singapore Workforce Development Agency (WDA), Singapore Economic Development Board (EDB) and Biopharmaceutical Manufacturers' Advisory Council (BMAC) unveiled a manpower roadmap for the fast-growing biologics manufacturing industry. The Sectoral Manpower Development Plan (SMDP) for biologics manufacturing was jointly developed by the WDA, EDB and BMAC, with the support of industry players, including AbbVie, Amgen, Baxter, GlaxoSmithKline, Lonza, Novartis and Roche. The plan examined the future demand and supply of skilled manpower and available career progression and recommended a set of strategies to meet the demand for skilled workers, improve the relevance of training programmes, and attract and retain talent.

The biomedical strategy has translated into jobs in Singapore. The biomedical manufacturing industry has also shown the fastest employment growth since 2000 (7.77%) in comparison with the overall manufacturing sector (0.68%) and the whole of the Singapore economy (3.14%). In 2019 biomedical manufacturing employed 24,384 people, 65% in medical technology manufacturing and 35% in pharmaceuticals.

Infrastructure Provision

For its biomedical strategy the Singaporean government invested significant funds into infrastructure at the dual hubs of the manufacturing centre at Tuas and the knowledge, development and research centre at Biopolis.

During the first five years, most of the Biopolis space was dedicated to public research buildings, although co-location of public–private research institutes was encouraged, while in the second stage new Biopolis facilities were marketed to private companies. Today, Biopolis comprises 13 buildings with a total floor area of over 34 hectares. This resides within a broader knowledge hub composed of different technology sectors known as one-north. The 200-ha one-north estate began its 20-year phased development in 2000 to house a cluster of research facilities and business parks. In 2019 the development contained 50,000 workers, 8 districts, 190 buildings, 16 public research institutes, 6 institutes of higher learning, 400 companies, 800 start-ups and 3,900 residents.[89] The cluster has been designed as a multi-use zone, with office clusters interspersed with pockets of housing, live–work spaces, retail and parks.[90] Conveniences include restaurants, a day-care centre, a fitness centre, a business hotel, shuttle buses and even a pub.

Opened in 1997, Tuas Biomedical Park (TBP) provided 370 ha of prepared land with ready-made infrastructure for pharmaceutical and biologics manufacturing, including access to roads, drainage power systems, power, water supply and telecommunication lines. Both parks were developed by the JTC Corporation, the lead agency in Singapore for the planning, promotion and development of industrial real estate. At TBP is located JTC Space, a 29,000-square-metre integrated development comprising industrial units, laboratories and shared meeting and training rooms. The development is suitable for biomedical companies requiring ready-built space to set up manufacturing operations. Underlying this provision is the excellent Singaporean infrastructure, including world-class transport infrastructure, services and connectivity.[91]

Co-location of Public Institutions

An important feature early in the development of the Biopolis precinct was the use of co-location of public institutions to contribute to the critical mass of knowledge infrastructure present in the precinct. While co-location is implied in the notion of a cluster, co-location with *public institutions* is significant for Biopolis, and it is worth highlighting explicitly for this case study. It is argued that the establishment of these institutes within the initial stages of Biopolis provided the initial critical mass to enable the continued attraction of other companies, including multinationals.

Biopolis was placed in an area close to the National University of Singapore, schools, science parks, the National University Hospital and residential areas.[92]

The complex houses 11 of Singapore's 12 biomedical research entities: the Bioinformatics Institute (BII), the Bioprocessing Technology Institute (BTI), the Genome Institute of Singapore (GIS), the Institute of Bioengineering and Nanotechnology (IBN), the Institute of Molecular and Cell Biology (IMCB), the Experimental Drug Development Centre (EDDC), the Singapore Bioimaging Consortium (SBIC), the Singapore Immunology Network (SIgN), the Singapore Institute Of Food And Biotechnology Innovation (SIFBI), the Skin Research Institute of Singapore (SRIS) and the Institute of Medical Biology (IMB) (soon to close).[93] They share the park with the national Bioethics Advisory Board, A*STAR and Bio*One Capital.

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[89] JTC (2019). A guide to one-north.
[90] MIT Centre for Real Estate (2004). New Century Cities Case Studies – One-North.
[91] WEF (2018). The Global Competitiveness Report.
[92] MIT Centre for Real Estate (2004). New Century Cities Case Studies – One-North.
[93] A*STAR (2020). Biomedical Research Entities. *Agency for Science, Technology and Research, Singapore.*

Box 8: Public institutes established in Biopolis in the early years of Singapore's biomedical strategy[94]

- 2000 – Genomics Institute of Singapore (GIS)
- 2000 – Biomedical Research Council (BMRC)
- 2001 – Bioinformatics Institute (BII)
- 2001 – Singapore Health Sciences Authority
- 2002 – Singapore Tissue Network (STN)
- 2002 – Institute of Bioengineering and Nanotechnology (IBN)
- 2004 – Regional Emerging Diseases Intervention (REDI) Centre
- 2004 – The Centre for Molecular Medicine (CMM)
- 2004 – Chemical Process Technology Centre (CPTC)
- 2005 – Chemical Synthesis Laboratory
- 2005 – Singapore Stem Cell Consortium
- 2006 – Bioimaging and Stem Cell Laboratories
- 2007 – Singapore Institute for Clinical Sciences (SICS)
- 2007 – Clinical Imaging Research Centre
- 2007 – Institute of Medical Biology (IMB)

A Core Competency

Unusually, while Singapore had a chemical pharmaceutical manufacturing presence in the country, initially it did not have an existing competency in biomedical sciences from which to grow a cluster. For this reason, the role of the Singaporean government was critical for cluster development.

Multi-pronged strategies were put in place to address this, as detailed throughout this report. Singapore's Biomedical Sciences Executive Committee was advised by the International Advisory Council, comprising eminent scientists from around the world. As discussed below, senior international experts were attracted in the early stages, and Singaporean scientists were supported to train abroad. Government agencies leveraged their spending power to produce proof-of-concept companies with biomedical manufacturing capabilities. The R&D budget was significantly increased, purchases were made by government to create a seed of biomedical manufacturing capacity, and foreign direct investment in biomedical R&D was actively courted.

A Supportive Regulatory Environment

Singapore often ranks highly in terms of ease of doing business, global competitiveness and the low burden of its regulatory environment. It performed best on burden of government regulation, property rights and corporate governance in the World Economic Forum's Competitiveness Rankings.[95] Some academics have suggested that it is the policy and regulatory frameworks that have led to Singapore's success in comparison to similar locations, such as Hong Kong.[96]

[94] Wong et al. (2010). Industrial Cluster Development and Innovation in Singapore. *From Agglomeration to Innovation,* pp. 50–116.
[95] WEF (2018). The Global Competitiveness Report.
[96] Mercurio & Kim (2015). Foreign Direct Investment in the Pharmaceutical Industry: Why Singapore and not Hong Kong.

For the biosciences industry, the Bioethics Advisory Committee (BAC), which was formed in 2000, developed recommendations on the legal, ethical and social issues of human biology research, which eventually led to the regulatory environment underlying the biomedical strategy. For example, in 2005 the government accepted the Bioethics Advisory Committee's paper "Genetic Testing and Genetic Research". The Health Sciences Authority (HSA) is the national authority regulating health products in Singapore, and the Genetics Modification Advisory Committee (GMAC) was established in 1999.[97]

Sophisticated Demand

As a result of the lack of a large internal market, a sophisticated strategy was required to position the demand for the Singaporean biomedical strategy. The approach that continues to be taken is an appeal to multinationals with interests in the ASEAN region as a whole, with Singapore pitched as an ideal hub for expansion and management in these markets.

Business Capabilities

In 2020 Singapore ranked second on the Ease of Doing Business rankings developed by the World Bank,[98] and over the last decade Singapore has stayed at the top of *The Economist*'s Business Environment Rankings.[99] It came second in the World Economic Forum's Competitiveness Rankings.[95] While fewer ratings are available prior to implementation of the Biomedical Strategy, in the 1999 and 2000 Global Competitiveness Reports Singapore ranked first and second, respectively,[100] indicating a similar level of business capability across this time period.

Culture

The design of Biopolis encourages sharing between business and research, and the embedding of residential facilities has been marketed as part of a lifestyle package to attract international talent. There is limited evidence around the development of a culture within the Singaporean Biopolis over time, and as such this study refrains from drawing conclusions on this aspect of the cluster.

The cluster does, however, appear to be attempting to foster this collaborative culture between researchers, businesses and end-users, with a number of centres, memoranda and consortia. For example, co-location of the Biopolis site with the National University of Singapore, the National University Hospital, the Lee Kong Chian School of Medicine and the Duke-NUS Graduate Medical School offered close links to potential users of newly developed biomedical products and services.

During the second stage, two academic medical centres were formed, which brought together large hospitals and their companion medical schools (National University Hospital, Duke-NUS and Singapore General Hospital). This initiative included the creation of an investigative medicine unit at each academic medical centre, the creation of a national imaging centre dedicated to clinical research and the formation

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[97] Wong et al. (2010). Industrial Cluster Development and Innovation in Singapore. *From Agglomeration to Innovation,* pp. 50–116.
[98] The World Bank (2020). Doing Business, Economy rankings.
[99] *The Economist* (2018). Business Environment Rankings.
[100] MIT (2000). The Global Competitiveness Report. *World Economic Forum.*

of a national clinical trials network that brought public medical health-care delivery systems together under one umbrella organisation.

LESSONS FROM THE SINGAPOREAN BIOMEDICAL STRATEGY

In addition to the importance of the supporting policies outlined above, several lessons for policy can be drawn from the Singaporean case study. These include the importance of a well-coordinated government strategy, proactive and patient policy options, and the use of clusters as a tangible investment destination. It also highlights key factors of the Singaporean context, which may limit translation of these lessons into other national contexts.

The Singaporean Context

This section highlights facets of the Singaporean context that may be relevant for those looking to translate the findings from this case study into their own environments.

The use of English is widespread in Singapore, as a first language in the education system, and English has been promoted as the country's language of administration since independence. Literacy levels in Singapore vary widely; however, young adults perform above the OECD average, and they are among the best-performing countries in numeracy.[101] Two Singaporean universities – the National University of Singapore and the Nanyang Technological University – were ranked in the top 100 universities in the world in 2020, at 25th and 47th, respectively.[102]

There is high political stability in Singapore, with the People's Action Party in power continuously since the 1960s. Press freedom is limited, with Singapore ranked 158th out of 180 countries.[103] Nonetheless, Singapore is seen as one of the least corrupt countries globally, ranking fourth among 180 countries, alongside Finland and Sweden.[104]

Singapore’s population mix of Asian ethnic groups makes it conducive to developing new treatments and technologies, as well as drug trials customised to Asian populations, although many countries in the region are competitive on track records and with larger domestic markets.[105] Critics note the small domestic market of Singapore – similar to Switzerland or Scandinavian countries – which requires a strategy to leverage the value created outside Singapore.

Proactive Policy

Singapore has relied on a strategy of attracting FDI from global multinational corporations.[106] Significant proactive government intervention was in play in the early stages of the Biopolis cluster – from attracting international manufacturing capabilities and international talent to early government investment, which planted the seeds for an industrial R&D and manufacturing presence.[107]

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[101] OECD (2016). Skills Matter: Further results from the survey of adult skills: Singapore.
[102] For comparison, LSE ranked 27th, KCL 35th and Manchester 51st. *Times Higher Education* (2020). World University Rankings 2021.
[103] Reporters Without Borders (2020). World Press Freedom Index.
[104] Transparency International (2019). Corruption Perception Index, 2019.
[105] Sandstrom (2009). Singapore, aiming to create the Biopolis of Asia, *VINNOVA.*
[106] Wong (2001). Leveraging multinational corporations, fostering technopreneurship: the changing role of S&T policy in Singapore. *International Journal of Technology Management*, Vol 22, No 5/6, pp. 539–567. Wong (2005). From technology adopter to innovator: the dynamics of change in the national system of innovation in Singapore. In Edquist & Hommen (eds). *Small Economy Innovation Systems: Comparing Globalization, Change and Policy in Asia and Europe*, Edward Elgar, Cheltenham.
[107] Case studies detailing similar proactive government investment leading to FDI can be found in the Results section.

For example, back in 2000 Singapore's EDB team visited Novartis in Basel, Switzerland. A Novartis team visited Singapore the following year, and once an agreement had been reached, in 2002 the first employee started work at Biopolis. In 2004 Novartis established in Biopolis the Novartis Institute for Tropical Diseases (NITD), a small molecule drug discovery research institute dedicated to finding new medicines to treat neglected infectious diseases such as dengue haemorrhagic fever and tuberculosis.

The government also played a key role in investing in A-Bio, a public research institute that would later be the base for Singapore's first biologics manufacturing private contractor, publicly funded in the form of equity. This organisation would later contribute to bringing one of the largest biologics manufacturing plants into Singapore, GSK's S$600 million vaccine manufacturing plant, which employs 1,000 skilled workers.

Patient Policy

Singapore's biomedical sciences hub initiative can be framed within the government's systematic efforts to increase investments in R&D, beginning in 1990 with the creation of the National Science and Technology Board, as well as with the adoption of five-year R&D investment plans.[108]

The notion of patient policy was highlighted by the Royal Society as a supporting factor for a successful cluster[109] because of the long timescales required for returns. This patience rings particularly true for investments in areas with historically long lead times, such as drug development and discovery. For example, for Humira, the first US biologics-based drug that achieved large market adoption, it took 31 years from the initial research by Sir Gregory Winter in 1977 to FDA approval in 2008. While the biomedical science strategy has not yet delivered revenue through drug discovery, it has certainly contributed to job creation and manufacturing value added.

Coordinated Policy

The government of Singapore took a proactive role in developing the country's biomedical manufacturing industry. In looking to make Singapore a hub for biomedical sciences, the government focused on attracting talent, investment and activity across the entire manufacturing value chain, "from basic research to clinical trials, product/process development, full-scale manufacturing and health-care delivery".[110] This involved a concerted state initiative through the Economic Development Board (EDB), the Agency for Science, Technology and Research (A*STAR), the Ministry of Trade and Industry, the Ministry of Education, the Ministry of Health and the National Research Foundation.[111] Of these, the EDB and A*STAR, through the Biomedical Research Council (BMRC), played pivotal roles in the early stages.

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[108] Poh (2016). From Research to Innovation to Enterprise: The Case of Singapore, A*Star. In Dutta S., Lanvin B. & Wunsch-Vincent S. (eds). *The Global Innovation Index 2016, Winning with Global Innovation,* World Intellectual Property Organization, Cornell University, INSEAD: Ithaca, Fontainebleau and Geneva.
[109] The Royal Society (2020). Research and Innovation Clusters.
[110] Wong et al. (2010). Industrial Cluster Development and Innovation in Singapore. *From Agglomeration to Innovation,* pp. 50–116.
[111] Fischer (2018). A Tale of Two Genome Institutes: Qualitative Networks, Charismatic Voice, and R&D Strategies—Juxtaposing GIS Biopolis and BGI. *Science, Technology, and Society, 23*(2).

Clusters as Tangible Investment Destinations

The ability to attract manufacturing FDI to Singapore was supported by a clear, specific and tangible opportunity, which was made real by the Biopolis and Tuas sites. Despite Singapore's small size – less than half the area of London – its decision to pursue a strategy based on a physical cluster speaks to the power of co-location for attracting companies.

Clearly identifying its value proposition early on, a strong tradition of supporting the promotion of both the site and Singapore as an investment location more broadly has continued over the years. This pitch was supported by the EBD, which has 19 foreign offices from which to promote opportunities.[112]

In the Biopolis and Tuas sites the Singaporean government invested in developing a physical location, which made the commitment to the biomedical sciences tangible, and the purpose-built facilities and ready-made infrastructure serve to increase the confidence of investors.

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[112] Singapore Economic Development Board (2020). Global offices.

Appendix 1

TABLE 6 – SECTOR CLASSIFICATION USED TO DEFINE BIOMEDICAL MANUFACTURING

Sector	SSIC Code/Division	SSIC Code/Definition
Pharmaceutical	21. Manufacture of pharmaceuticals and biological products	2101: Manufacture of pharmaceutical products 2102: Manufacture of biological products 2103: Manufacture of traditional Chinese medicine
Medical technology	26. Manufacture of computer, electronic and optical products	2660: Manufacture and repair of irradiation, electromedical and electrotherapeutic equipment
	32. Other manufacturing	3250: Manufacture and repair of irradiation and electromedical equipment and instruments

Source: Department of Statistics, Singapore (2018) Singapore Standard Industrial Classification 2015 (version 2018).

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About us

Policy Links is a global not-for-profit innovation policy consultancy unit that works with governments to develop effective industrial innovation policies. We offer new evidence, insights and tools based on the latest academic thinking and international best practice in the areas of technology, manufacturing and innovation policy, with a track record of delivering high-impact projects in both developing and developed countries around the world.

Policy Links is part of IfM Education and Consultancy Services (IfM ECS), which is owned by the University of Cambridge. Profits are gifted to the University of Cambridge to fund future research activities. Cambridge Industrial Innovation Policy (CIIP) brings together the Centre for Science, Technology & Innovation Policy at the Institute for Manufacturing, the Policy Links Unit from IfM ECS and the Babbage Policy Forum.

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About this policy brief

This policy brief is part of a series of studies produced for the Gatsby Charitable Foundation.