From Research to Innovation to Enterprise: The Case of Singapore

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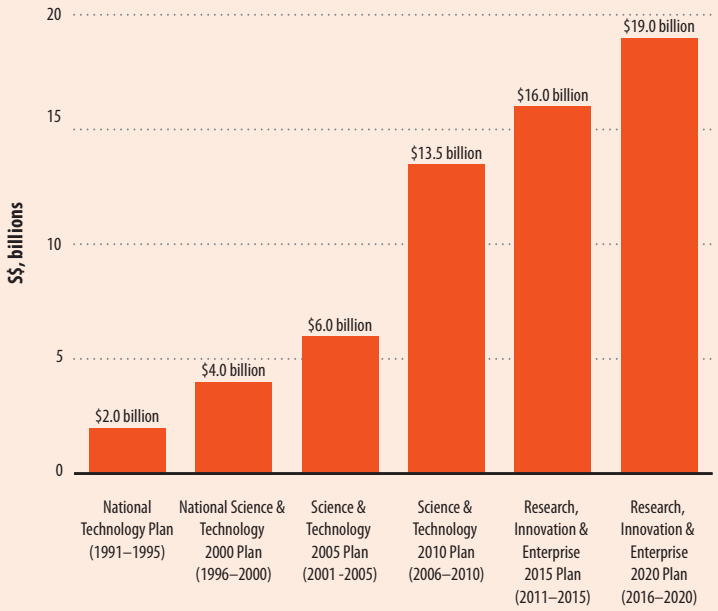
In just 50 years, Singapore has transformed itself from a developing economy with few natural resources to a thriving global metropolis. Its gross domestic product (GDP) per capita has risen from US$516 in 1965 to US$52,888 in 2015.[1] In 2015, Singapore celebrated its Golden Jubilee and the nation came together to reflect on how far the country had come and to envision the future. This chapter aims to shed light on a critical element of Singapore's success story: the country's investments in research and innovation.

Figure 1: Singapore's public R&D budget, 1991 to 2020



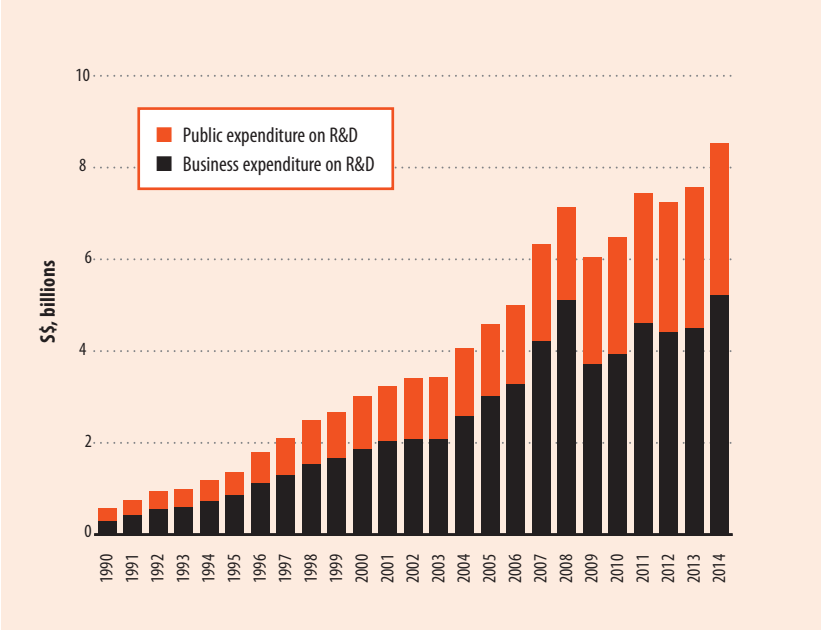
Source: National Research Foundation, RIE2020 Plan, available at http://www.nrf.gov.sg/research/rie2020.

Singapore's research and development journey

Since Singapore's independence in 1965, the government understood that it had to develop science and technology (S&T) capabilities to overcome the constraints of the country's limited size and lack of natural resources in order to ensure its economic survival. In 1966, the late founding Prime Minister Lee Kuan Yew said at the opening of the Science Tower in the University of Singapore, 'our population ... is the one thing we have which makes up for our lack of size and numbers, and it is of the utmost importance that, in the field of science and technology, we should lead the field in this part of the world.'[2] Singapore made early efforts to build research and development (R&D) capabilities, such as those under the Singapore Institute of Standards and Industrial Research (SISIR) formed in 1969. However, the economy was still predominantly capital- and skills-intensive before the 1990s.

It was with the establishment of the National Science and Technology Board (NSTB) in 1990 and the launch of the first five-year National Technology Plan in 1991 that the government began to invest in R&D in a significant and structured way (Figure 1). These developments followed the 1986 report by a national Economic Review Committee, set up after Singapore's first major recession in 1985. That report recommended that Singapore move up the economic value chain, away from low-cost competition in traditional manufacturing and services to develop new high-technology clusters and activities. Over the next 25 years, four more national S&T plans were implemented to position Singapore as an innovation-driven, knowledge-based economy. The S$19 billion *Research, Innovation*

Figure 2: Gross expenditure on R&D, 1990 to 2014



Source: National R&D Survey of Singapore 2014.

and Enterprise 2020 Plan (RIE2020) is the country's sixth five-year plan; announced by Singapore's Prime Minister Lee Hsien Loong in January 2016, it represents a nearly 10-fold increase in the public R&D budget over the S$2 billion National Technology Plan of 1991.

With strong government commitment to R&D and a steady stream of public funding, a rich and diverse research ecosystem has been built up in Singapore over the past two and a half decades. This ecosystem includes the research institutes of the Agency for Science, Technology and Research (A*STAR), which focus on mission-oriented research for economic impact; research-intensive universities that concentrate on academic research to develop a base of fundamental knowledge; and academic medical centres and hospitals that focus on translational and clinical research, as well as corporate labs.

Singapore has also launched major infrastructural initiatives to strengthen its research and innovation system. The one-north masterplan was conceived in 2001 to catalyse the growth of research-intensive hubs in the biomedical sciences and the physical sciences and engineering (in Biopolis and Fusionopolis, respectively),[3] where researchers from the public and private sectors could co-locate. In October 2015, with the completion of the state-of-the-art facilities at Fusionopolis Two, the one-north vision reached a meaningful milestone as a vibrant and dynamic hub: home to over 250 companies, 600 start-ups, 16 public research institutes, five corporate universities and institutes of higher learning comprising an internationally diverse community of 16,000 scientists, researchers, and innovators coming from both the public and private sectors. It is therefore heartening to note that Thomson Reuters has ranked A*STAR as one of the world's Top 25 Global Innovators (Government) at the 9th position.[4]

An outcomes-driven and phased approach

Singapore has taken a steady and sustained approach to funding R&D as a critical pillar of Singapore's economic development strategy (Figure 2). The public R&D budget has increased from S$2 billion under the 1991 five-year National Technology Plan to S$19 billion under the recently announced RIE2020 Plan. Annual public expenditure on R&D (PUBERD) reached S$3.3 billion in 2014, a compound annual growth rate (CAGR) of 11.1% over the past nearly two and a half decades (1990 to 2014). Correspondingly, annual business expenditure on R&D has grown at a CAGR of 12.5% over the same period, from $0.3 billion in 1990 to $5.2 billion in 2014, the highest level yet.

The development of Singapore's research and innovation system has been different from that of many other successful research-intensive countries around the world. Unlike the research and innovation systems of countries such as Switzerland and Germany, which grew organically out of centuries-old research-intensive universities or industries, Singapore's R&D push was predominantly a directed, government-led effort to upgrade and strengthen the competitiveness of the domestic economy. In other words, Singapore's R&D journey was rooted in a need for economic competitiveness and growth. Today its research and innovation policies continue to heavily emphasize economic outcomes and impact. Given the many competing needs for resources, Singapore also had to adopt a pragmatic, phased approach to its R&D initiative.

The launch of its National Technology Plan in 1991 provided the framework for establishing Singapore's science and engineering research institutes over the following 10 years. A key feature of these institutes was their purpose: they were set up to serve Singapore's manufacturing sectors, mainly electronics, engineering, and chemicals. By 2001 Singapore saw that the biomedical sciences presented tremendous growth potential. It started the Biomedical Sciences (BMS) Initiative to establish biomedical sciences as the fourth pillar of the manufacturing economy, alongside electronics, engineering, and chemicals. Between 2001 and 2005, Singapore put into place the key building blocks that would establish core scientific biomedical capabilities and attract the talent needed for the endeavour. In its second phase (2006–10), the BMS Initiative focused on strengthening biomedical science capabilities to bring scientific discoveries from the laboratory bench to the bedside, to improve human health and healthcare delivery, and to bring benefits to the economy and society.

From 2004 to 2006, concurrent with the launch of the second phase of the BMS Initiative, two successive reviews were conducted with the aim of transforming Singapore's public universities into autonomous and research-intensive institutions to enable them to respond to the increasingly competitive global academic landscape and become world-class research universities. This review led to a significant increase in funding for academic research, the setting up of an Academic Research Council, and the establishment of the Research Centres of Excellence (RCEs). Five RCEs were established within Singapore's two largest universities[5]—the National University of Singapore (NUS) and the Nanyang Technological University (NTU)—to attract world-class academic investigators, train high-quality research talent, and create new knowledge in the specific areas of each centre. In the process, the international standing of Singapore's universities rose significantly. In the 2016 *Times Higher Education* global university rankings, NUS was ranked 26th and NTU 55th, up from their respective positions 34th and 174th only five years before.[6]

In 2006, with a rapidly growing and diversifying research landscape, Singapore recognized the need for high-level coordination and strategizing of the research efforts. This led to the establishment of the Research, Innovation and Enterprise Council, chaired by the Prime Minister and comprising international and local members, to steer the overall direction of the strategy. The National Research Foundation was established at the same time to plan, coordinate, and monitor the execution of the strategy.

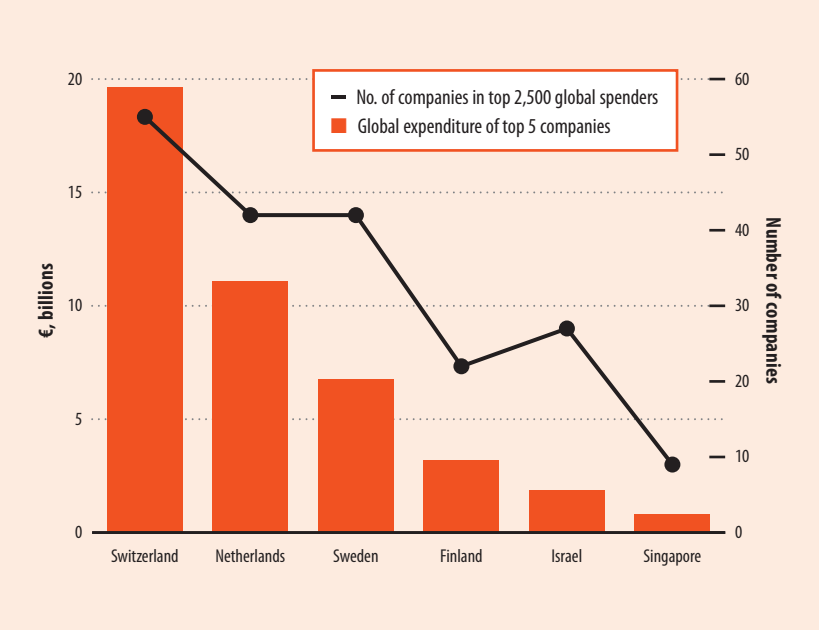
From research to innovation to enterprise (R-I-E)

In 2010, in the aftermath of the global financial crisis, Singapore undertook another review of its economic strategies to position itself for the new post-crisis environment and to achieve sustained and inclusive growth. Among other things, that review recommended strengthening its emphasis on business innovation and the commercialization of R&D, including creating customized platforms to facilitate the integration of the capabilities of research institutions, companies, and public-sector agencies to deliver innovative solutions. This approach gave rise to the pivotal articulation of Singapore's R&D framework—one that is based on open innovation—from research to innovation to enterprise.

The fifth national R&D plan—the Research, Innovation and Enterprise 2015 Plan (RIE2015) (2011–15)—espoused, for the first time, differentiated open innovation strategies targeted at the different enterprise segments that make up Singapore's economy. Singapore recognized then that its research ecosystem had progressed to another level of maturity, and a pipeline of promising research outputs had the potential to yield benefits. By recognizing that multinational corporations (MNCs), large local companies, small and medium-sized enterprises (SMEs), and start-ups each have different needs and capacities for conducting R&D and absorbing research outputs, Singapore embarked on customizing partnership models and open innovation platforms suited to their specific needs and circumstances. For example, the differentiated value proposition that Singapore was able to offer MNCs was the spectrum of science and engineering capabilities available within a small, compact location; seamless access to these capabilities across different research institutions; and the rich diversity of world-class talent present in those institutions.

In contrast, SMEs typically had limited resources available for R&D and were interested in new products or services that could bring additional revenue streams, or in productivity measures that could help them remain competitive. Public-sector efforts were then focused on either bringing technologies further down the value chain so they could be readily licensed by the companies or creating ready-to-go technologies that could be easily adopted. Consortia that brought these SMEs into the supply chains of larger MNCs

Figure 3: Comparison of corporate R&D expenditure across small research-intensive countries, 2014



Source: EU Industrial R&D Investment Scoreboard.

Table 1: Global expenditure of the top five corporate spenders as a percentage of national BERD, latest available year

Switzerland (2012)	Netherlands (2014)	Sweden (2014)	Finland (2014)	Israel (2014)	Singapore (2014)
164%	149%	74%	72%	23%	26%

Source: Estimates based on data from the EU Industrial R&D Investment Scoreboard; OECD Main Science and Technology Indicators; 2014 National R&D Survey of Singapore; and the European Central Bank.

Note: Percentage figures were estimated by dividing data from the EU Industrial R&D Investment Scoreboard (the numerator) by the national BERD (the denominator, which was estimated by multiplying BERD in the national currency, taken from the OECD and the 2014 National R&D Survey of Singapore, by appropriate exchange rates, taken from the European Central Bank).

were also a particularly useful model for ensuring that these smaller firms could raise their capabilities so they could continue to serve the MNCs.

The economic agenda has always been a fundamental tenet of Singapore's R&D strategy: all of Singapore's national S&T plans have consistently articulated the goal of catalysing private-sector investment and growth. Singapore has therefore adopted a holistic and integrated approach to developing research, innovation, and enterprise capabilities that allow it to translate research discoveries to impactful outcomes.

Singapore's strategy: Open innovation and open talent

Singapore's innovation system has been characterized by a strong openness to foreign investments, ideas, and talent. As a small, resource-constrained economy since its independence, Singapore recognized that it needed to tap into globalization to survive. Since the 1960s, the Singapore Economic Development Board (EDB) pioneered a strategy of welcoming and attracting MNCs and foreign direct investments into Singapore—at a time when many other countries were, at best, still largely ambivalent about foreign investment and corporations.

This attitude of openness has similarly been adopted in the R&D sector. When Singapore was building up its R&D capabilities in the early years, it relied on an open talent strategy to recruit international scientific leaders to seed capabilities and mentor young scientists. As a result, today Singapore has a robust core of local research talent complemented by a rich diversity of international talent. Of Singapore's research community, 30% are foreign,[7] allowing it to tap into the diversity of research ideas, expertise, and networks around the world. This puts Singapore among the most internationally diverse R&D ecosystems globally, on par with Sweden and the United Kingdom.

Another trend that Singapore has leveraged on in its R&D strategy is that of open innovation. As defined by Henry Chesbrough in 2006, 'Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively.'[8] Globalization, technological advances, increased connectivity, and intensifying competition have led many companies to turn away from the traditional Bell Labs approach of internal R&D.[9] Instead, companies embrace the open innovation model and partner more aggressively with public-research performers across the globe. For example, Procter & Gamble is an early adopter of open innovation models through their Connect+Develop programme. From 2000 to 2006, the programme

helped increase their R&D productivity by almost 60%, more than doubled their innovation success rate, and doubled their share price while lowering their cost of innovation: their R&D investment as a percentage of sales decreased from 4.8% in 2000 to 3.4% in 2006.[10]

Very early on, Singapore recognized and harnessed the benefits of open innovation by collaborating with and anchoring strategic MNC partners, thereby transferring their capabilities and expertise to the local ecosystem while creating good jobs in the local economy. Singapore's economic agencies, such as A*STAR and EDB, make coordinated efforts to leverage open innovation to strengthen Singapore's key industry clusters. For example, A*STAR and EDB successfully partnered with Applied Materials, the largest semiconductor equipment manufacturer in the world, to anchor the firm's R&D operations in Singapore. Today all wafer-level packaging research across the firm is conducted in Singapore, adding to Singapore's position as a key global node for semiconductor R&D.

Another example of Singapore's open innovation strategy that has led to industry growth is seen in the aerospace cluster. Under the A*STAR Aerospace Research Consortium, major aerospace MNCs (such as Airbus, Boeing, Pratt & Whitney, and Rolls-Royce), local leading companies, and A*STAR research institutes collaborate in pre-competitive research. The consortium has played a critical role in building the R&D expertise needed for Singapore's aerospace industry, allowing it to gain a competitive edge over other emerging hubs in the region.

In recent years, Singapore's research-intensive universities have also deepened their industry engagement with major collaborations including the Rolls-Royce@NTU Corporate Lab and Keppel-NUS Corporate Lab. In the health and biomedical sciences space, A*STAR, the universities, hospitals, and academic medical centres also collaborate closely in major translational and clinical research programmes that aim to bring R&D from bench to bedside. Many of these collaborations, which link research to innovation and enterprise, are also both inter- and transdisciplinary in nature. Singapore recognizes that the greatest impact of innovation is often found at the convergence of different research fields and professions. In particular, A*STAR has played a leading role in convening large-scale, multi-disciplinary programmes that integrate the diverse capabilities of various performers in the ecosystem.

Besides open innovation partnerships with companies, Singapore has attracted top research performers from across the world. For example, the Campus for Research Excellence and Technological Enterprise (CREATE) under the National Research Foundation houses research centres from top universities such as the Massachusetts Institute of Technology (MIT), ETH Zurich, Cambridge University, and Peking University. These international partnerships have created a strong pipeline of ideas, talent, and research capabilities to increase the vibrancy and diversity of Singapore's R&D ecosystem. Another example is the Asian Network for Translational Research and Cardiovascular Trials programme, in which A*STAR and the major public healthcare institutions collaborate with regional partners across 10 countries to study cardiovascular disease progression in heart failure.

Singapore's challenges: Private-sector innovation capacity

Singapore's R&D and innovation journey is not without its challenges. Although it has consistently ranked 1st in the Innovation Input Sub-Index of the Global Innovation Index, Singapore ranked 20th in the Innovation Output Sub-Index in 2015, leading to an overall Innovation Efficiency ratio ranking of 100th in that year. In particular, Creative outputs is an area of weakness in Singapore that needs to be improved on, hovering at 33rd place in both 2014 and 2015; Knowledge and technology outputs fared better, at 12th place in 2015.

This situation is partly a result of the relatively nascent and government-led development of Singapore's innovation system. The Singapore government invested significantly in developing the country's universities and public research institutions in order to catalyse private-sector investments. As a result, although public-sector research has grown in intensity and excellence, that of enterprises, especially local enterprises, has yet to grow at a corresponding rate. The MNCs, by and large, dominate in many R&D-intensive industry clusters, such as electronics, pharmaceuticals, and biomedical sciences. In comparison, local enterprises are still relatively modest in their research investments and capabilities, although their growth rate appears to have picked up in the last five years or so.

Another pertinent observation is that many of the most research-intensive and innovative small economies in the world (such as Switzerland, Sweden, and Finland) have large home-grown companies that are also multinationals in their own right—these domestic MNCs account for a major proportion of the business expenditure on R&D

(BERD), and are the engines of innovation as well as technology receptacles of the R&D outputs in their home countries (Figure 3, Table 1).[11] For example, in Sweden, about 80% of business R&D is performed by a few large multinational companies, and 49% of BERD spent by Swedish-owned MNCs.[12] In Finland, Nokia alone used to contribute almost half of BERD in its heyday.[13] In comparison, it takes more than 100 companies in Singapore to contribute 80% of BERD and the large local enterprises collectively contribute only 17%.[14] The stark difference illustrates plainly that Singapore's domestic enterprises are nowhere near as large or as research-intensive as those in other small research-intensive countries.

Singapore is well aware of this challenge and of the importance of local enterprises, both small and large, to a strong and sustainable economy. Indeed, Singapore's SMEs employ 70% of workers and contribute 50% of total GDP.[15] Therefore, in recent years, government policy makers have placed greater emphasis on the technological upgrading of SMEs. SPRING, an economic agency dedicated to helping Singapore's SMEs grow, offers a broad slew of incentives and credit schemes to encourage SMEs to conduct R&D. A*STAR also carries out programmes that support the transfer of technologies and expertise from its research institutes to SMEs. Examples include the Growing Enterprises through Technology Upgrade (GET-Up) programme, which helps companies with their technology roadmapping and attaches research scientists to companies to increase their absorptive capacity; and the Technology Adoption Programme, which encourages companies to adopt ready technologies that may help them improve productivity.

Singapore is also increasing its efforts to collaborate with large local companies. For example, in the marine and offshore sector, Singapore is building a deepwater ocean basin and will partner with the industry, including local shipyards, to grow prototyping and testing capabilities for offshore platform development. More recently, companies outside the manufacturing sector—such as the DBS Bank and Singtel—have stepped up to collaborate with public-sector performers to enhance the digitization and data analytics capabilities within the banking and telecommunication sectors, respectively.

In addition, Singapore is stepping up its efforts to develop its entrepreneurial ecosystem. Assistance schemes such as the Technology Incubation Scheme, Early Stage Venture Funds, and the Technology Enterprise Commercialisation Scheme provide funding support for companies in their early stages. Within the one-north area, the government has built dedicated infrastructure for start-ups at the JTC Launchpad, which houses a growing number of successful local information technology and biomedical start-ups. Indeed, start-ups in Singapore have more than doubled in the last decade, growing from 24,400 in 2005 to 55,000 in 2014. The Global Entrepreneurship and Development Institute's annual Global Entrepreneurship Index now ranks Singapore as the 11th most entrepreneurial country.[16] However, Singapore's start-up scene is still far from the likes of Silicon Valley or Israel, and there is much room to inculcate more entrepreneurial mindsets in young Singaporeans and catalyse more start-up activities.

There is a silver lining in all these endeavours: Many local companies are now aware of the benefits that R&D and innovation can bring to their businesses, especially as they seek to differentiate their products and services from the competition. The aspiration is that, with continued persistence and more success stories of local enterprise growth, Singapore's private-sector innovative capacity will close the gap with the top research-intensive countries in the world. Singapore has some way to go in terms of cultivating a vibrant, R&D-intensive private sector, but it is on the right trajectory.

Conclusion: The way forward for Singapore

Singapore's R&D efforts have led it to be consistently ranked in the top 10 in the Global Innovation Index. It came in 7th in the 2015 GII, the top-ranked country in the South East Asia and Oceania region. Singapore ranked 1st in the Innovation Input Sub-Index and is seen to be strong in the Infrastructure and Business sophistication sub-pillars, in which it ranked 1st for each pillar. Its strong performance in the GII rankings is undergirded by strong growth in gross expenditure on R&D (GERD) and BERD, as shown earlier. The impact of these R&D investments is evident in the creation of many high-value jobs for the Singapore economy, with 32,835 research scientist and engineer (RSE) jobs in 2014, a growth of 6% CAGR over the last 10 years.[17]

Interestingly, because of the way Singapore's R&D sector has developed—through a government-led effort aimed at catalysing private-sector activities and investment—the Business sophistication pillar is viewed in Singapore as an output of its public R&D endeavours rather

than as an input. Many of the indicators in this pillar, such as knowledge-intensive employment and the state of cluster development, are in fact key performance indicators for the government agencies undertaking research activities.

Under the RIE2020 Plan announced earlier this year, Singapore has shifted to a governance framework that would allow for even more integrated national strategies, as well as strengthened links between the country's research capabilities and industry structure. Under RIE2020, Singapore is organizing its R&D investments into four thematic domains that reflect major national challenges and economic opportunities: Advanced Manufacturing & Engineering; Health & Biomedical Sciences; Urban Solutions & Sustainability; and Services & Digital Economy. This structure provides coherence to the research endeavours of the various research performers, the public-sector agencies, and the private sector. At the same time, three cross-cutting programmes—academic research, manpower, and innovation and enterprise—will support the four domains. The intent naturally is to avoid unnecessary duplication of effort, to support the most meritorious ideas and proposals, and to achieve even greater outcomes for the steady and sustained investments of the government in RIE2020.

Notes

1 Department of Statistics, Singapore, SingStat Table Builder, available at http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=3252.

2 Josey, 2012, p. 325.

3 Information about one-north can be found at http://www.jtc.gov.sg/industrial-land-and-space/pages/one-north.aspx.

4 Thomson Reuters, 2016.

5 The three RCEs hosted in NUS are the Cancer Science Institute of Singapore, the Centre for Quantum Technologies, and the Mechanobiology Institute. The two RCEs hosted in the NTU are the Earth Observatory of Singapore and the Singapore Centre on Environmental Life Sciences Engineering.

6 See the Times Higher Education World University Rankings, available at https://www.timeshighereducation.com/world-university-rankings/2016/world-ranking.

7 This refers to the percentage of foreigners among PhD, Masters, Bachelors, and non-degree researchers. National R&D Survey of Singapore 2014.

8 Chesbrough, 2006, p.1.

9 Information about the Bell Labs approach can be seen in Hilger, 2014.

10 Huston and Sakkab, 2006.

11 OECD, 2013, p.165

12 Jacob et al., 2015. The *RIO Country Report 2015: Sweden*, released 23 June 2016, uses data from 2013.

13 OECD, 2008, p. 116.

14 National R&D Survey of Singapore 2014.

15 Say, 2015.

16 The Global Entrepreneurship Index can be found at https://thegedi.org/global-entrepreneurship-and-development-index/.

17 National R&D Survey of Singapore 2014.

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Thomson Reuters. 2016. *The Top 25 Global Innovators: Government.* Available at http://stateofinnovation.thomsonreuters.com/the-top-25-global-innovators-government#.