Securing Australia's Future - Project 9
Translating research for economic and social benefit: country comparisons

Singapore

Improving Commercialization of Publicly-Funded Research: Singapore

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For:

ACOLA
AUSTRALIAN COUNCIL OF LEARNED ACADEMIES

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1. Introduction

This paper aims to review Singapore's approaches to commercialization of publicly-funded research and study the effectiveness of these approaches. Comparison of a range of commercialization measures will highlight their key success factors and help develop a roadmap for translating public research to products with economic and societal value. The study has been possible owing to the support of Australian Council of Learned Academies (ACOLA), a non-profit organization formed by Australia's four independent learned academies, to support evidence-based interdisciplinary research.

Study Scope

Before diving into commercialization measures, this study details the history of Singapore's research and development (R&D) efforts. It is important to understand how the landscape of R&D players and their role in the ecosystem affect R&D policy design and execution. The national R&D thrusts are also studied to gain an understanding of the national R&D context and motivations.

The success factors of commercialization measures are analyzed using case studies on initiatives, funding schemes, and policy changes. Case studies are also used to identify the factors that have helped Singapore in commercializing its public R&D. Each case study details the rationale for implementation, nature of the measure, costs involved, and outcomes arising from implementing the measure. Where possible, the success rates of each measure are identified using relevant indicators.

Research Methodology

The insights have been drawn from an analysis of available literature: Research studies, news articles, national announcements, and published data. The findings have also been confirmed and supplemented by Eden's formal and informal engagements with policy makers over the past five years. In particular, this study engages those policy makers who are involved in policies relating to the commercialization of R&D activities.

2. Executive Summary

Singapore is a young country with limited natural resources. When multinational corporations (MNCs) first started setting up their operations locally, they would transfer their technologies and best practices to their Singapore facilities. As a result, from the 1970s – 80s, the country invested very little in research and development (R&D) activities.

However, the attractiveness of basing low-value added manufacturing activities out of Singapore reduced, as operating costs rose. MNCs began to locate high-tech manufacturing activities in Singapore. These activities needed to be supported by deep research expertise. Singapore, therefore, started prioritizing R&D activities, to become an attractive location for MNCs.

The government started investing heavily in R&D starting from the 1990s. Singapore's manufacturing sector also started evolving in line with R&D investments; labor-intensive in the 1960s, skill-intensive in the 1970s, capital-intensive in the 1980s, and technology-intensive in the 1990s. The nation shifted towards a knowledge and innovation-based economy in the 2000s. This period also marked the beginning of investments in the Biomedical Sciences sector.

Since the launch of the first National Technology Plan in 1991, Singapore's expenditure on R&D has increased almost tenfold. The initial focus of R&D spending was on growing research manpower and building infrastructure. Subsequently, the focus shifted to developing R&D capabilities by training talent and developing technologies needed for conducting research in the long-term. Singapore's current emphasis is on industry partnerships and on producing economic outcomes from public research. To this end, the Research Innovation Enterprise Council (RIEC), the body that sets the strategic direction for national R&D, dedicated 70 percent of Singapore's five-year R&D budget to achieving economic outcomes in 2015, five percent more than the budget five years ago. It is evident that innovation and enterprise form the cornerstone of Singapore's strategy to remain globally competitive.

We have structured Singapore's good practices in public research commercialization as six organizing principles:

1. **Coordinating R&D Activities across Government Agencies**
2. **Using Funding to Seed and Support the Most Promising Ideas or Researchers**
3. **Fostering Cross-Industry Collaboration**
4. **Aligning Stakeholder Incentives to Realize Commercialization Outcomes**
5. **Supporting and Scaling Commercialization Outcomes**
6. **Setting up a Supportive Ecosystem for Commercialization**

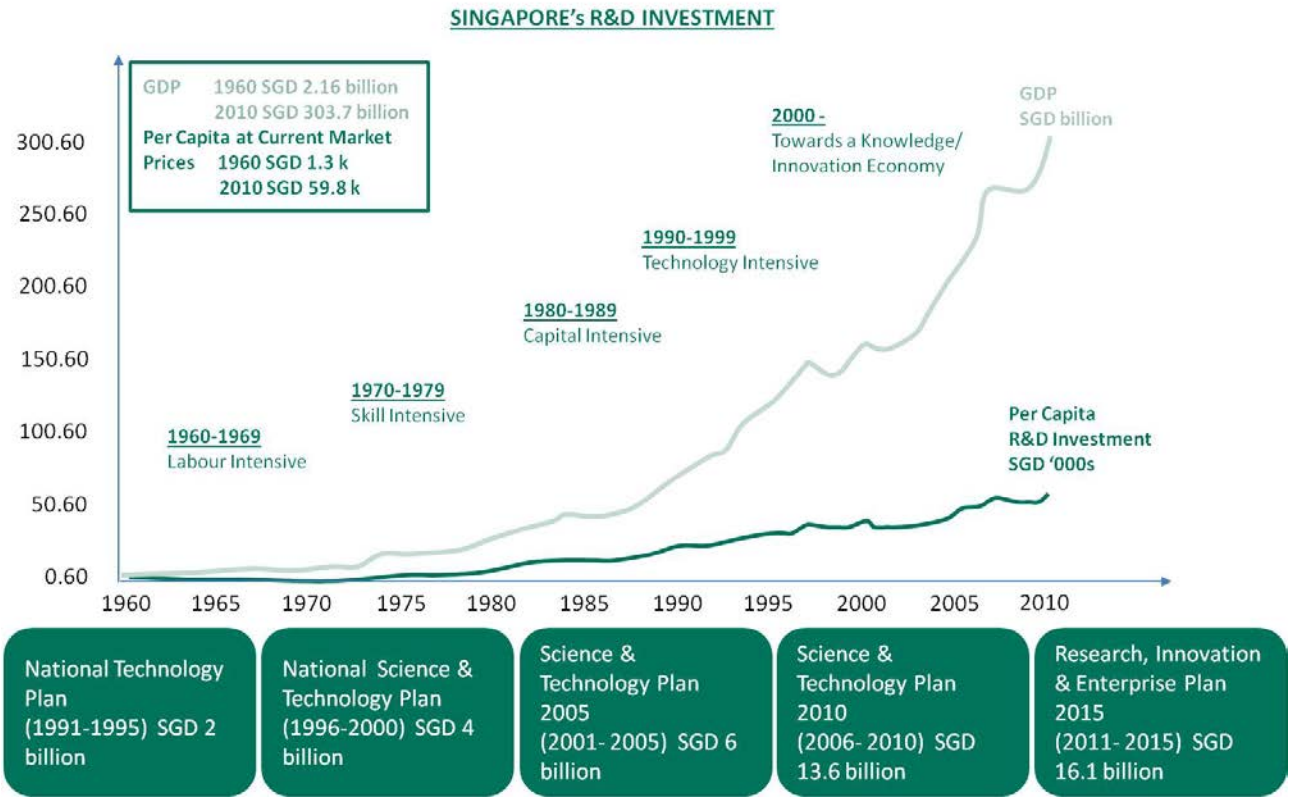
Singapore's R&D policies are formulated by RIEC and the National Research Foundation (NRF). NRF acts as a secretariat to RIEC, and helps in **coordinating R&D activities across different government agencies**. An example of this cross-agency coordination will be detailed in the National Innovation Challenge case study. NRF provides an overview of R&D in Singapore, and helps shape the policies, research areas, and initiatives to support these areas. It also evaluates, approves, and monitors project proposals submitted through other government agencies. RIEC advises the cabinet on the strategic direction for Singapore's R&D efforts. Together, RIEC and NRF provide funding to different government ministries, who then allocate finances to schemes within their purview in order to **seed and support the most promising ideas or researchers** as observed in the NRF Fellowship case study. The schemes are availed by public sector researchers such as autonomous universities (e.g. Nanyang Technological University, National University of Singapore) and A*STAR's research institutions. However it is important to **foster cross-industry collaboration** in order to involve more private sector players leading to industry relevant research. As a result, private sector players also benefit from the funding, using it to set up their R&D functions in Singapore as observed in the Productivity and Innovation Credit case study, or even jointly invest in research facilities with public universities and research institutions as detailed in the Corporate Laboratory@University case study.

It is then necessary to **align stakeholder incentives to realize commercialization outcomes.** The case study on NUS Enterprise's Industry Liaison Office (ILO) illustrate part of this alignment where researchers, universities, and private sector players work together to commercialize the research output. Singapore has also developed programmes to **support and scale these commercialization outcomes** as we can see in the ILO case study, where support is given to researchers to further develop spin-off companies. Various infrastructure, talent, and R&D schemes, in unison, aim to produce outcomes that strengthen Singapore's strategic industry clusters. In parallel to supporting research activities, the government also dedicates resources to develop a holistic ecosystem for R&D; this includes funders, intermediaries, and knowledge exchange platforms. **Setting up this supportive ecosystem for commercialization** can be observed with the Early Stage Venture Fund (ESVF) case study.

Public research commercialization requires the alignment between Singapore's national interests and R&D strategy. As a result, research priorities are identified based on their strategic implications on the economy. Research efforts are also aimed at diversifying Singapore's economic landscape, increasing the innovativeness of its people, and presenting an attractive destination for multinationals to establish their offices.

The nation is able to orchestrate its vision by coordinating a multitude of research initiatives and governing agencies, using competitive funding to filter outstanding ideas, championing collaborations between the public and private sectors, aligning all stakeholders to achieve commercial outcomes, and providing the necessary support for scaling public research commercialization.

3. Singapore's Evolving R&D Strategy



Immediately after independence, Singapore faced high unemployment rates due to the inability of trading activities to create enough job opportunities for the nation's populace. As a result, the government's prime focus then was to implement industrialization policies, involving labour-intensive activities, with little priority given to inculcating a creative workforce.

In the 1990s, after almost twenty years of undergoing rapid industrialization, Singapore's economic landscape had developed significantly. It was also clear that industrial policies that focused on maintaining trade surplus, through a heavy reliance on exports, would eventually make the economy vulnerable to fluctuations in global demand for exported goods. Therefore, in developing the resilience of Singapore's economy, the government focused on enterprise development as a means to achieve economic growth and to establish global competitiveness. In view of this, knowledge creation and technology development were recognized as the key enterprise development pillars. This was further emphasized by the launch of the first National Technology Plan in 1991.

	1991 – 1995	1996 – 2000	2001 - 2005	2006 - 2010	2011 - 2015
NATIONAL PRIORITIES	**MANPOWER, INFRASTRUCTURE**	**CAPABILITY DEVELOPMENT**	**CAPABILITY DEVELOPMENT , INDUSTRY ENGAGEMENT**	**INDUSTRY R&D, LINK PUBLIC R&D AND INDUSTRY**	**RESEARCH COLLABORATIONS, COMMERCIALIZATION OF R&D RESULTS**
5-YEAR S&T PLAN	National Technology Plan (NTP)	National Science & Technology Plan (NSTP) – Securing our Future	Science and Technology 2005 (S&T2005) Plan	Science and Technology 2010 (S&T2010) Plan – Sustaining innovation-driven Growth	RIE2015
BUDGET	SGD 2 billion	SGD 4 billion	SGD 6 billion	SGD 13.6 billion	SGD 16.1 billion
KEY THRUSTS	•Develop a technology infrastructure •Support of private sector R&D •Develop R&D manpower	Deepen long-term technological capabilities and engage in medium- and longer-term technology development	•Strengthen R&D capabilities in targeted areas •Nurture local talent and recruiting global talent •Promote industry	•Focus on selected areas of economic importance •Balance investigator-led and mission-oriented research •Encourage more private sector R&D •Strengthen linkage between R&D and business	•Emphasis on basic science as the basis for future innovations •Focus on talent attraction and development •Greater emphasis on competitive funding to select better ideas •Foster synergies between R&D in public and private sector •Greater proportion of R&D dedicated to economic outcomes •Strengthen the support for commercialization to develop new products and services

In the early years, R&D was aimed at achieving scientific excellence and growing the local knowledge base. However, as a small country, with a limited budget, the government realized that R&D activities cannot be solely focused on basic research. Singapore had to identify its own unique strengths and play by them. One of Singapore's competitive advantages is its attractiveness to multinationals targeting Asian markets. R&D activities can greatly support multinationals that are establishing high value-added functions in Singapore. This would eventually also help grow Singapore's economy and boost the nation's competitiveness.

As a result, the R&D efforts are dedicated towards producing economic outcomes that can further support private sector players. The research priorities are also carefully chosen to support Singapore's economic ambitions. Singapore's strategic research priorities are therefore identified based on:

- Areas that are not only useful to Singapore but to the whole world
- Research that will help build Singapore's competitive edge
- Areas that can position Singapore to tap on emerging technologies that promote economic growth

In view of the aforementioned criteria, Singapore's R&D efforts are dedicated to the following areas:

a. **Biomedical Science**

b. **Electronics**

c. **Chemicals**

d. **Precision Transport Engineering**

e. **Infocomms and Media**

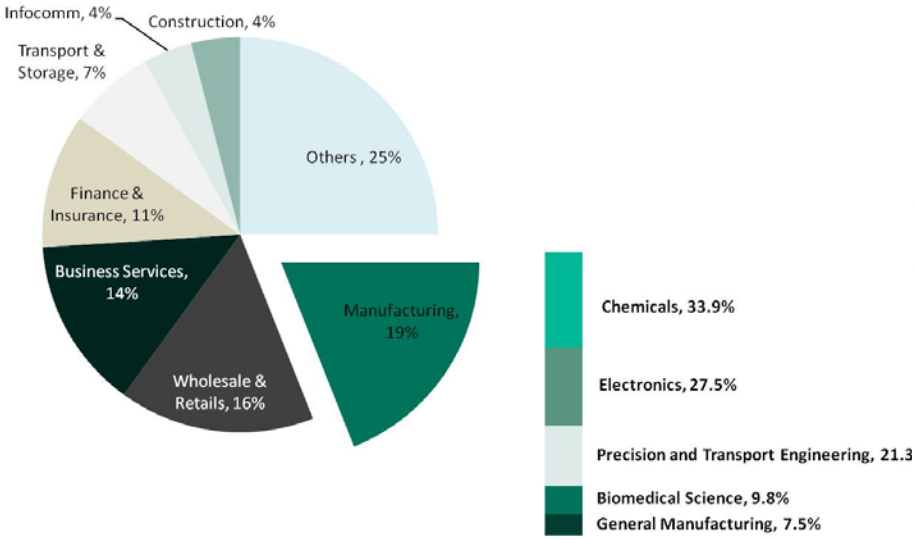
f. **Others (e.g. Food sciences, energy, earth & related environmental sciences)**

Prioritization of research areas and devising R&D policies that catalyze the commercialization of publicly-funded research has helped Singapore in achieving its strategic objectives.

Despite these efforts, Singapore faces a few challenges in commercializing R&D activities. These stem from inherent differences in incentives of public sector researchers and private sector players. Researchers often care the most for scientific excellence while industry-led research prioritizes commercial outcomes. As Singapore transitions to an innovation centered economy, it is still in the process of setting the right incentives for all its R&D stakeholders. The small size of Singapore also adds to challenges in creating a regular pipeline of R&D spin-offs and associated economic multipliers.

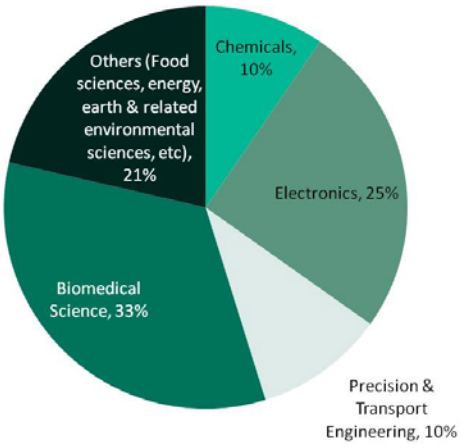
In order to overcome these challenges, Singapore will need to further identify its role in the global R&D ecosystem. A more focused R&D approach, based on its strengths, will help Singapore effectively implement existing R&D commercialization measures.

SNAPSHOT OF SINGAPORES ECONOMY



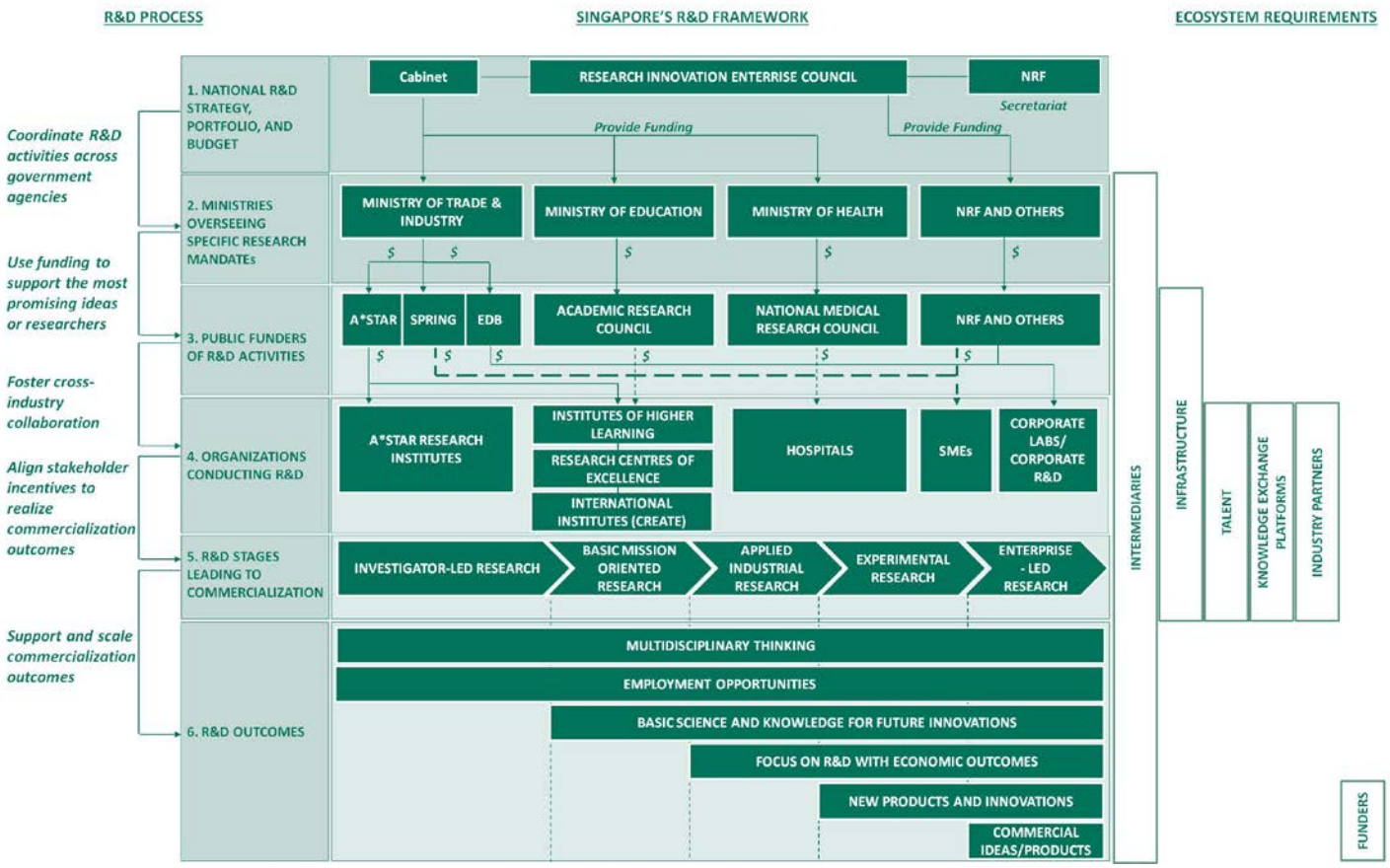
Source: MTI 2012 Statistics

PUBLIC EXPENDITURE ON R&D



*Source: A*STAR R&D Survey 2011*

4. Organizing Public R&D in Singapore



1. *National R&D Strategy, Portfolio, and Budget*

The strategic direction of Singapore's R&D is decided by the Research, Innovation, and Enterprise Council (RIEC), a body set up in 2006. This council is chaired by the Prime Minister, and it advises Cabinet Ministers on national research and innovation strategies in five distinct areas – Public R&D, Private R&D, Innovation and Enterprise, Talent, and Infrastructure. The National Research Foundation (NRF) supports the RIEC by coordinating R&D efforts across government agencies, and supporting the development of national policies to support Singapore's capabilities.

2. *Ministries Overseeing Specific Research Mandates*

Each Ministry oversees different research areas based on their mandate. Ministries allocate funds to agencies under them, and set guidelines for granting funds.

a. **Ministry of Trade and Industry (MTI).** MTI coordinates research through its agencies – A*STAR, SPRING, and EDB. MTI is primarily focused on mission-driven research, rather than general research.

b. **Ministry of Education (MOE).** MOE oversees research carried out in academic institutions, especially investigator-led research. This class

of research is targeted to develop broad-based understanding of various topic areas, and building knowledge resources over a extended period of time.

c. **Ministry of Health.** The MOH's key mandate is to drive the translation of basic research to advanced medical applications that improve the quality of life. It aims to boost the translational and clinical research facilities of medical researchers, hospitals, and research institutions.

3. Public Funders of R&D Activities

With support from the Ministry of Finance, various Ministries and government agencies control the disbursement of funds for areas of research that fall within their scope. Councils such as the Academic Research Council (ARC) under MOE use funding schemes as vehicles to provide financing to promising researchers.

a. **A*STAR.** A*STAR is the lead agency responsible for cementing Singapore as a knowledge/innovation economy. It comprises 21 public research institutes that are invested in translating research outcomes to practical applications. A*STAR is deeply-involved in growing knowledge in biomedical sciences, physical sciences, and engineering. It is also responsible for growing the local pool of PhD talent that can be readily tapped by industry partners.

b. **Economic Development Board (EDB).** EDB's key mandate is develop Singapore's economy, and one of its related activities is to encourage MNCs to set up their R&D and innovation functions in Singapore. It provides funding, incentives, and advice to MNCs who are looking to expand their global footprint in Asia.

c. **SPRING Singapore.** SPRING invests in the R&D development of Small and Medium Enterprises (SMEs). SPRING works with local enterprises, provides them with grants for capability development and technological empowerment. SPRING also works closely with local companies to provide them with mentoring and business advice for scaling their outreach.

d. **Academic Research Council (ARC).** The ARC operates under MOE, and was established to strengthen the research efforts especially at the university level. It also advises MOE on the appropriate research funding that should be allocated to the Academic Research Fund (AcRF). This fund is meant to support research that can improve the international reputation of universities, provide quality education to students, develop knowledge resources with future potential, and provide quality manpower for research purposes.

e. **National Medical Research Council (NMRC).** The NMRC was established to nurture clinical research at

medical institutions and hospitals. It is also responsible for awarding research funding and recognizing top medical talent.

f. **National Research Foundation (NRF)**. In addition to devising national R&D policies and strategies, NRF also provides funding for different initiatives. For instance, the NRF Fellowship Scheme provides grant support to researchers from any nationality, to carry out independent research based out of Singapore.

4. Organizations Conducting R&D

R&D efforts can be channeled through either, the public and private sectors, or in joint sector initiatives. Each government agency works with relevant stakeholders who conduct research, to reinforce the R&D strategic thrusts as defined by RIE.

Public R&D players comprise of the 21 public research institutions and Corporate Laboratories under A*STAR, public universities under the Institute of Higher Learning, hospitals and medical centres, and other government labs. The Campus for Research Excellence and Technological Enterprise (CREATE) at The National University of Singapore (NUS) also houses research programs set up by various international universities.

Private players are typically R&D labs of companies and industry players, involved in specific research relating to their core products and services. Corporate Lab@University supports industry relevant partnerships between universities and industry partners. EDB and A*STAR support multinationals in basing their R&D and innovation functions out of Singapore. In parallel, SPRING works with SMEs through seven Centres of Innovation (COIs), supporting them in the R&D aspects of their businesses.

5. R&D Stages Leading to Commercialization

The motivation and objectives of research determine the likelihood of creating a product with commercial value. Research can be investigator-led, wherein the investigator proposes the research topic, sources for funding, and develops research outcomes. It may alternatively be industry-led, which often involves a market need that drives targeted solutions from R&D efforts. Corporate Labs @University are examples of companies that wish to leverage academic research, facilities and talent to conduct directed research for a specific market gap.

a. **Investigator-led Research.** Research Centres of Excellence (RCE) were set up to attract world class investigators to perform high-quality research, and are focused on investigator-led research. Several funding schemes, such as the New Investigator Grant, are also meant to attract more researchers to enter this sector. This type of research aims to create a rich knowledge base over a period of time. It also helps in developing research talent.

b. **Basic Mission-Oriented Research.** This class of research is usually done to develop a broad understanding of various research topics, with the hope that the understanding may lead to practical solutions in the future. A*STAR drives mission-oriented research that leads to scientific discovery and innovation.

c. **Applied Industrial Research.** This class of research is done with an upfront practical goal, and can address the challenges faced by industry players. It helps bridge the gap between academia and industry.

d. **Experimental Research.** This class of research involves systematic approaches to create more innovative products, which work better than their existing alternatives.

e. **Enterprise-led Research.** The research problem is defined by industry players, and research efforts are aimed at finding solutions to that problem. The commercialization potential of research outcomes is more significant in this case.

6. R&D Outcomes

Research activities should reinforce the R&D strategy, and help achieve outcomes that are aligned with national priorities. Singapore's Science & Technology thrusts show the evolution of R&D priorities from developing infrastructure and manpower, to creating products and services with commercial value. RIE 2015 defined six key objectives of all R&D activities in Singapore, with a heavy focus on efforts that help in realizing economic benefits of research. All R&D actors work towards the common goal of delivering on these outcomes.

a. **Multidisciplinary Research.** More collaborative research is facilitated by providing a higher funding quantum to institutions that are embarking on initiatives that facilitate multidisciplinary research, through A*STAR's Joint Council Office that received an expanded five-year budget of SGD 250 million in 2010.

b. **Employment Opportunities.** Singapore is a small country and may not have enough local talent to meet its R&D targets. As a result, it invests in bringing top scientific talent from different parts of the world, nurturing homegrown talent through overseas scholarships and local university programs, and also attracting overseas Singaporean researchers through its Returning Singapore Scientists Scheme.

c. **Focus on Basic Research.** One of the focus areas for Singapore's RIE strategy is to develop a knowledge base on topics that scientists are passionate about. This knowledge could potentially form the basis of future innovations. The AcRF has been enhanced to encourage more investigator-led research.

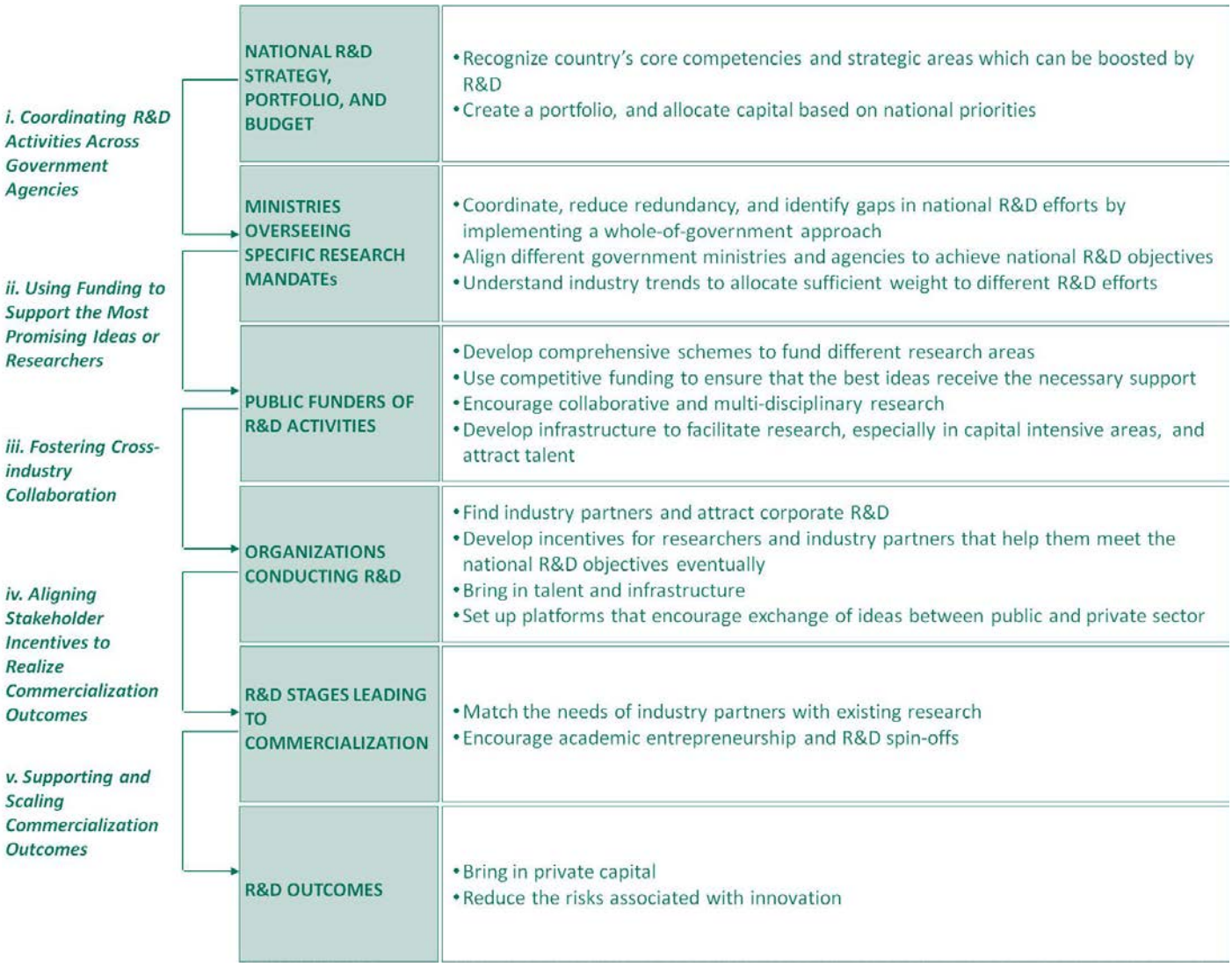
d. **Focus on R&D with Economic Outcomes.** A new SGD 1.4 billion Industry Alignment Fund was set up to foster closer alignment of research with industry, while the five-year private R&D budget was increased from SGD 2.1 billion to SGD 2.5 billion in 2010.

e. **New Products and Technology.** The RIE had committed to doubling its Innovation and Enterprise budget to SGD 1.1 billion between 2010 and 2015, helping scientists to take their work from an idea stage to a commercial product or company, with the support of innovation centres, Technology Transfer Offices, enterprise incubators, and accelerators.

f. **Prioritizing Superior Ideas for Funding.** Competitive funding continues to receive emphasis as it helps filter the best ideas. A greater proportion of R&D has been allocated to competitive funding, while maintaining enough budget for core activities. The five-year budget for NRF's Competitive Research Programme was expanded from SGD 350 million to SGD 1 billion in 2010.

S&T 2010 Performance Indicators for A*STAR		Achieved (as of 31st March 2011)
HUMAN CAPITAL DEVELOPMENT		
1	No. of PhD students trained and graduated	555
2	No. of Research Institution staff spun out to locally based industry	1,058
INTELLECTUAL CAPITAL DEVELOPMENT		
3	No. of primary patents filed	1,170
4	No. of papers published (in Science Citation Index and Engineering Index journals)	15,978
INDUSTRIAL CAPITAL DEVELOPMENT		
5	No. of industry projects	1,554
6	Industry funding (SGD million)	219.5

5. A Roadmap for Successful Public Research Commercialization



The competitiveness of Singapore's industries depends on their ability to innovate. Therefore research and innovation lie at the heart of Singapore's national strategy. In the same vein, achieving innovation and economic outcomes underscore Singapore's R&D strategy; starting from setting the R&D priorities all the way to scaling R&D outcomes.

In addition to a clear national mandate towards commercializing public research, there are five key success factors that greatly help Singapore execute its R&D strategy.

a. **Coordinated R&D activities across government agencies.** Despite having different research mandates, different government agencies continue to overlap in their R&D efforts. For instance, both SPRING

and A*STAR have funding schemes to support small enterprises and startups. Similarly, there are biomedical science groups under A*STAR, EDB, and MOH. In order to avoid redundancies in R&D efforts and harness synergies among similar initiatives, it is important to coordinate the R&D efforts of different government agencies. The agencies are also responsible for providing feedback to RIE on existing research policies, to contribute to improving their outcomes.

b. **Availability of funding for the most deserving researchers.** Ministries and their corresponding agencies are given specific budgets to carry out their R&D activities. Competitive funding helps in filtering only the most promising ideas through, and supporting these ideas with the necessary funds. Singapore's government has been increasing the availability of funding by increasing the budget for schemes such as NRF's Competitive Research Programme from SGD 350 million to SGD 1 billion.

c. **Cross-industry collaboration.** The government has been increasingly investing in increasing collaboration across researchers belonging to different organizations: Universities, CREATE, A*STAR research institutes, hospitals, and industry. A*STAR's Joint Council Office encourages multidisciplinary research. Similarly, events such as The Global Young Scientists Summit @one-north convene different members of the R&D community, and help in increasing the cross-pollination of ideas.

d. **Aligned incentives across all stakeholder groups.** Singapore has shifted from being heavily-focused on industrial research, to becoming more innovation-focused. As a result, there is a need to design incentives that balance basic research, while maintaining emphasis on applied industrial research. In addition, industry players and public researchers inherently have different motivations for performing research. Industry players may care more for economic outcomes, while public researchers may be more attracted towards opportunities to publish. Hence, funding schemes can help in establishing the right Key Performance Indicators (KPIs) that would help deliver outcomes that are most crucial in promoting national R&D interests.

e. **Support and scale commercialization outcomes.** Commercializing public research does not only involve finding practical applications of the research. Its true success hinges on the rapid adoption of the application via commercial business models. Therefore, once the product is conceived in a R&D laboratory, it needs funding support and business

advisory to become truly successful. Private sector partners need to be incentivized to provide monetary and non-monetary support to R&D spin-offs. Especially given the context of an Asian society with low risk tolerance, the government needs to explicitly nurture innovation, even if it involves taking calculated risks. Over time these efforts can help develop an innovative society that will embrace entrepreneurial risks. Success stories of organizations that benefitted from Singapore's R&D infrastructure helps attract more organizations that are thinking of expanding their Asian presence.

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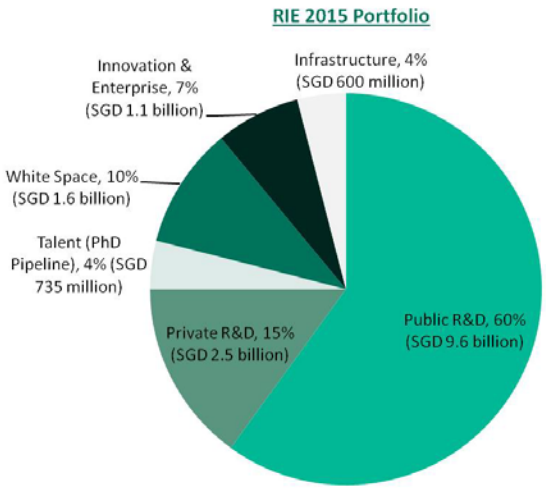
i. Coordinating R&D Activities across Government Agencies



R&D activities require many different actors in order to create economic impact. Various government agencies need to be involved in bringing together actors from the public and private sectors. In addition, the initiatives offered by each organization have to be coordinated and aligned to best capture opportunities for economic impact.

To illustrate this, Singapore's Biomedical Science (BMS) Cluster, conceived in the 2000s, has implemented a Whole-of-Government approach to effectively tap on the strengths of multiple stakeholders.

The initial years in the growth of the BMS sector entailed building the right infrastructure and attracting talent. This was the first phase of BMS development that took place between 2001 and 2005. A*STAR, along with the support from other agencies, was responsible for developing infrastructure for R&D. At the same time, EDB started the Biomedical Science Group Bio*One Capital to attract BMS multinationals to set up their R&D in Singapore. A*STAR was keen to meaningfully direct the BMS efforts by identifying gaps in existing research. Coordination became necessary given the involvement of different stakeholders. As a result, the Biomedical Sciences Executive Committee (BMS Exco) was set up in 2006 to lead the second phase of Singapore's BMS initiative. During the second phase, from 2006-2010, the focus shifted towards translational and clinical research facilities

Therefore, Singapore's BMS sector's growth trajectory shows that Whole-of-Government efforts become particularly important when the sector attains enough traction to attract diverse set of players, and can benefit from harnessing the synergies among different actors.

PROGRAMME HIGHLIGHT: Biomedical Sciences Executive Committee

Challenge: The involvement of multiple stakeholders and a fast-growing BMS sector in Singapore necessitated the need to coordinate the research landscape, identify research gaps, promote R&D policies, and monitor the progress of the BMS ecosystem.

Approach: The BMS Executive Committee brought together key agencies such as A*STAR, MOH, MTI, and MOE. This helped in shifting the focus from conducting basic research, to instead working with MOH to find clinical applications of laboratory discoveries. This was meant to result in the discovery of new diagnostic tests, vaccines, and drugs, aimed at improving the quality of healthcare. Three working committees were set up in order to achieve these outcomes: The Intellectual Capital Working Group developed capabilities, regulations, and resources to carry translational research effectively; The Human Capital Working Group was responsible for building a pool of scientists, researchers, and doctors; and The Infrastructure Working Group looked into the physical and scientific infrastructure needed to enable BMS efforts.

Outcomes: As a result of the BMS Executive Committee's efforts, the BMS manufacturing industry has grown to become the fourth pillar of Singapore's economy and the leading manufacturing sector contributing 25.5% of the total manufacturing Value-Add with a production output of SGD 29.4 billion in 2012, nearly five times more than is 2000 with only SGD 6 billion. Employment for BMS manufacturing sector also increased from 6,000 employees in 2000 to 15,700 in 2012.

ii. Using Funding to Seed and Support the Most Promising Ideas or Researchers

The proportion of R&D budget available as competitive funding has increased in order to filter the best ideas, and support high-quality research efforts.

a. **Capability Development.** Singapore relies heavily on attracting and growing its pool of talent in order to sustain high-quality research activities. The NRF Fellowship was launched to fuel Singapore's talent attraction strategy. NRF Fellowship targets early-stage researchers to carry investigator-led research independently from Singapore. NRF Investigatorship, unlike the Fellowship, is meant for mid-career researchers with an excellent track record of research achievements, to incent them to pursue high-risk and disruptive research. By placing the Fellows in tenured positions in Singapore's universities and Research Centres of Excellence (RCE), the government creates a win-win situation for both the researchers and the local universities.

In terms of research talent, Singapore also encourages international companies to set up Research & Development (R&D) centers. These centers usually start by employing a high proportion of international talents brought by the company and gradually transfer knowledge to local talents by hiring them or via research collaboration with universities and research institutions.

Singapore uses several tax-incentive schemes to attract R&D centers such as the Transport Technology Innovation Development Scheme (TIDES) and the Pioneer Incentive Scheme. Tax incentives also apply to local SMEs, encouraging them to embark in R&D projects. The Productivity and Innovation Credit (PIC) gives up to SGD 400,000 tax deductions and allowances on targeted activities of which R&D activities is part.

CASE STUDY: Attracting top international research talents

Programme: NRF Fellowship

Challenge: As a small country, Singapore needs to attract top research talent in local universities to perform their research activities.

Programme and Process: The NRF Fellowship was launched to address Singapore's talent gap. The Fellowship invites Fellow applications once a year, to identify high potential candidates who are capable of producing breakthrough research. The Fellows are attached to a Singapore-based university or Research Centre of Excellence. Each Fellow is provided with a research grant capped at SGD 3 million that lasts for a period of five years, and allows them to carry out independent research.

The NRF Fellowship supports research in Infocomm Technologies and Interactive Digital Media, Engineering, and Life Sciences and Natural/Physical Sciences. The funding is only for post-doctoral research conducted from Singapore.

Candidates must first define the scope of their research and get an endorsement by a local research institution or university. They submit their application to the NRF portal (RITA) and undergo a two-round selection. The applications are first reviewed by the host institutions before being approved by the RF Fellowship Evaluation Panel (FEP).

NRF's selection criteria are:

- Top quality research talent with excellent scientific credentials as an outstanding researchers in his/her early stage of research careers
- Readiness to take on a first independent research appointment, usually having completed and demonstrated outstanding performance during a first post-doctoral fellowship stint at a renowned university
- Research project proposal demonstrating world-class scientific excellence
- Potential and aspiration to rise as a research leader in his/her field
- Willingness to commit to carrying out cutting-edge research on a full-time basis in Singapore if selected.

Efforts and Outcomes: This programme has been launched in 2007. Over the past nine years NRF has received over 1,000 applications from all over the world, of which 63 NRF Fellows have been selected through eight calls for collaboration. NRF has set stringent selection criteria and less than 10 percent of the applicants are enrolled in the programme each year. These Fellows are currently full-time professors at local universities where they share their knowledge with the local research community.

Key takeaway: The NRF Fellowship encourages top talents locally and worldwide to conduct deep post-doctoral research in Singapore. However, this programme has a long-term horizon as the research is independently-led and might not always have direct applications in industry. As a result it is difficult to quantify financial returns and impact.

CASE STUDY: Reducing the cost of R&D investment for SMEs

Programme: Productivity and Innovation Credit (PIC)

Challenge: SMEs are sometimes hesitant to invest in R&D and technology due to the time horizon to develop a true competitive advantage. As a result many SMEs have difficulties developing the deep innovation capabilities necessary to compete globally.

Programme and Process: The Inland Revenue Authority of Singapore (IRAS) introduced the PIC scheme in order to reduce the financial investment in six key activities:

- Acquisition or lease of IT and automation equipment
- Employee training
- IP registration such as Patents, Trademarks, and Designs
- Acquisition and Licensing of Intellectual Property Rights (IPR)
- Research and Development (R&D) Activities
- Design Projects Approved by DesignSingapore Council

Under the PIC Scheme, businesses can enjoy 400 percent tax deductions and allowances and 60 percent cash payout for investments made in any of the six qualifying activities from the years of assessment 2013 to 2018. From the years 2013 to 2015, businesses can also enjoy the PIC Bonus which is a dollar-for-dollar matching cash bonus capped at SGD 15,000 and given on top of the existing tax deduction, allowance, and cash payout.

The PIC also restrict the incentive to R&D activities which:

- Acquire new knowledge; create new products or processes; or improve existing products or processes
- Involves novelty or technical risk
- Involves a Systematic, Investigative and Experimental (SIE) study in a field of science or technology

Efforts and Outcomes: This programme has been launched in 2010 as part of a suite of tax incentives with a total budget of SGD 5.5 billion over five years. In 2014, the PIC has been extended until 2018 with an additional SGD 3.6 billion.

The PIC is one of the most well-known incentive programmes due to its high tax deduction and cash bonus. In 2012 alone 44,000 SMEs have used the PIC, a 21 percent increase from 2011.

In a survey conducted among SMEs in 2014, 87 percent of the respondents had used the PIC with 71 percent agreeing that it helped incentivize greater productivity investment, 40 percent agreeing that it had helped them to defray the costs on an usual investment, and 13 percent stating that it had helped with both objectives.

Key takeaway: The PIC has successfully convinced SMEs to look at technology in order to gain in productivity and build a competitive advantage. However SMEs have mostly used the grant for the acquisition of hardware and IP rather than R&D activities, which might be due to the generous reimbursement of technology solutions which can go up to 160 percent which is more attractive than a R&D initiative which deliver results over a longer period. Tax incentives to stimulate R&D work well on the short and medium term but must be well-designed to encourage long term commitment rather than one-off support.

b. Encouraging Multidisciplinary Thinking.

Solutions to complex problems often require multidisciplinary thinking. Similarly, R&D activities aimed at solving complex problems of national interest require the convergence of expertise from different disciplines.

Singapore government recognizes the importance of multidisciplinary thinking, and incentivizes R&D activities involving researchers with different backgrounds using suitable funding schemes. The National Innovation Challenge (NIC), by NRF, is a platform that involves Singapore's research capabilities in diverse areas, by involving multiple government agencies and researchers with a Whole-of-Government approach.

Similar to NIC, the Competitive Research Program (CRP) set up by NRF also fosters multidisciplinary teams, interested in solving national problems, to convene. Principal Investigators need to be from the Institutes of Higher Learning, while industry players and other entities can participate as collaborators.

CASE STUDY: Aligning nationwide research with the national agenda

Programme: National Innovation Challenge (NIC)

Challenge: Difficult, complex problems faced by Singapore as a nation, such as energy efficiency, environmental sustainability, and urban systems, require the combined intelligence of different disciplines. Since each research area is handled by a relevant government agency, there is a need to coordinate efforts across multiple agencies as well.

Programme and Process: The NIC was set up by NRF to tap on multidisciplinary thinking as a means to find solutions to complex national problems. It brings together the whole of government, with key agencies pursuing efforts in pertinent areas to the problem. The NIC fund focuses on three main research areas by funding lead agencies:

- Energy**.** SGD 300 million budget over five years (2011-2015)
- Land and Liveability**.** SGD 135 million over six years (2013-2018)
- Cybersecurity**.** SGD 130 million over five years (to be announced)

For each focus area, an executive committee is formed to allocate NRF's funding to the agencies and institutions. Each committee is free to structure its programme and decide on the budget allocation within the challenge area.

Efforts and Outcomes: This programme was launched in 2011 with a budget of SGD 1 bn. As in 2015, approximately half of the budget has been allocated to the three executive committees which have led their own projects.
The Energy NIC has developed the Green Building Innovation Centre (GBIC) in collaboration with the Building and Construction Authority (BCA) for a total of SGD 52 million. The GBIC's mandate is to demonstrate energy efficient solutions, act as the repository of the national building energy efficiency, and provide capability building programmes.
The Land and Liveability NIC has opened a call for collaboration and awarded 10 research projects out of the 78 received. The committee, advised by international experts, has divided the research into three workgroups; Space creation, Space optimization, and ICT platforms.
The National Cybersecurity R&D Programme is a joint-effort of NRF, the Ministry of Defense (MINDEF), the Ministry of Home Affairs (MHA), the National Security Coordination Secretariat (NSCS), the Infocomm Development Authority (IDA), and the Economic Development Board (EDB). Under this programme, research projects are awarded with a maximum funding of SGD 10 million for a five year timeframe. So far seven projects have been awarded for a total of SGD 34.5 million.

Key Takeaway: Despite its recent launch the NIC has already brought large research projects in line with the national agenda. The allocation of the fund through independent committees composed of the main industry stakeholders allows a faster and more efficient usage of the fund to steer the research towards market-oriented solutions.

Singapore, therefore, uses funding to encourage competent ideas involving multidisciplinary thinking.

c. **De-risking Innovation.** NRF recognizes the importance of de-risking innovation, both for the innovator as well as the funder. To encourage companies to explore the viability of R&D ideas, Proof-of-Concept and Proof-of-Value grants are provided. NRF and SPRING administer this grant for university/polytechnic researchers and SMEs respectively. Under this company, the grant recipient receives up to SGD 250,000 to test their initial prototypes for a technological innovation. NRF has also helped increase the availability of private sector capital, and reduce the risk profile of investments by setting up funds such as the Early Stage Venture Fund (ESVF) and the Technology Incubation Scheme (TIS). These funds allow technology incubators to co-invest with NRF, to reduce the risk exposure of the incubator. In addition, the incubator provides mentoring, working space, and other forms of non-monetary support.

Although Singapore has successfully encouraged many incubators to invest in the early stage companies, there is still a lack of pipeline of investible companies. As a result, the government has been taking steps to increase the pool of investible startups in Singapore, such as with the introduction of early-stage grant schemes and the development of the JTC Launchpad@ One-North project.

CASE STUDY: De-risking early stage investment in start-ups

Programme: Early Stage Venture Fund (ESVF)

Challenge: Technology incubators are reluctant to invest in companies with new and unproven ideas. Since R&D efforts focus on new approaches to existing problems, they often have little track record of success. Yet, for laboratory ideas to bloom into viable commercial solutions, they need funding, especially in the initial stages of growth.

Programme and Process: ESVF was launched by NRF to encourage more early stage investments into technology startups in Singapore by reducing the investor's risks. Under the scheme NRF invests SGD 10 million to SGD 15 million on a 1:1 matching basis with other private sector incubators. In order to incentivize investors, NRF proposed an attractive profit distribution scheme: NRF will only take profits up to five percent rate of return (based on simple interest), and any surplus profits can be distributed to the other investors depending on the amount of investment made. However in the event of a downside, the NRF funding, which capitalizes the investees, offers a first-loss protection to reduce risk for fellow investors.

The ESVF's evaluation panel comprises of established public and private industry executives such as Chu Swee Yeok, CEO of Economic Development Board Investments, Steven Leonard, executive deputy chairman of IDA, and Philip Ong, the deputy CEO of NRF.

Efforts and Outcomes: This programme has been launched in 2008 with an initial budget of SGD 50 million to support five venture capital firms, and has been enhanced in 2014 with another SGD 48 million supporting six more venture funds.

Until 2015, the scheme has enabled over 20 companies to be funded by the 11 participating venture capital firms, of which three have been acquired. For example HungryGoWhere, an online food portal, has been acquired in 2012 for SGD 12 million by Singapore Telecommunications Limited (SingTel). Other start-ups have subsequently received follow-up funding from other investors. For instance, Clearbridge Biomedics has received SGD 9 million in funding from other private and government funds.

Key Takeaway: The ESVF was initially launched at an early maturity stage of Singapore's start-up scene but has now met a growing demand of start-ups looking for Series A investments. It is a successful measure to reduce the investment risk in early stage companies in mature start-up ecosystems.

iii. Foster Cross-Industry Collaboration

Singapore greatly values collaboration between the public and private sectors, as a means to translate R&D outcomes into commercial solutions. This is especially important given that the government has increased its budget for projects that are likely to achieve economic success from 65 percent to 70 percent in the RIE2015 plan. Of the total available R&D budget of SGD 16.1 billion, SGD 1.4 billion has been set aside for the Industry Alignment Fund. This fund aims to strengthen public-private collaboration by setting up platforms for multidisciplinary research, consortia, and partnerships with the private sector.

a. **Infrastructure Investment for Encouraging Collaboration**

In addition to providing funding for cross-sector collaborative partnerships, NRF has also developed facilities, in the form of Corporate Laboratory@ University, where industry partners and researchers can work side-by-side. This will in turn benefit the private sector, by providing them resources to carry forward their research activities. At the same time, research talent can gain useful industry experience. NRF co-invests in these laboratories with industry partners to incentivize them to participate in this scheme.

CASE STUDY: Bridging the gap between academic research and industry application

Programme: Corporate Laboratory@University

Challenge: The private and academic sectors tend don't always collaborate effectively which leads to difficult industry applications and a low Technology Readiness Level.

Programme and Process: Corporate Laboratory@University is a one-off grant launched in order to nurture close collaboration between private sector players and public-funded researchers. This helps in ensuring that R&D efforts are dedicated towards producing commercial goods and services. Under this program, corporations set up their labs inside university premises and equally co-funded by NRF and the industry partner. NRF supports these labs with manpower, equipment, and other operating expenses in collaboration with the university. The industry partner matches the grant funding provided by NRF.

This program supports the effective translation of laboratory work to the industry by leveraging the skills of researchers, the faculty, Master's and PhD students. The program also helps in training researchers and students as they work in an industry environment.

Efforts and Outcomes: This programme has been launched in 2008 and led to the creation of five corporate laboratories with a total of over SGD 100 million invested by NRF followed by the equal amount by the industry partners:

- Rolls-Royce@NTU Corporate Laboratory with a SGD 75 million investment
- Keppel-NUS Corporate Laboratory with a SGD 75 million investment
- Imaging Biomarker Development Lab with a SGD 15 million investment
- Urban Computing and Engineering Lab @ SMU with a SGD 54 million investment
- ST Engineering@NTU Lab

The corporate laboratories are each driving research projects involving students, researchers, professors, and industry partners. For example the Rolls-Royce@NTU Corporate Laboratory has divided the research into three areas being electrical power and control systems; manufacturing and repair technologies; and computational engineering. NTU has set up a five-year roadmap to complete 32 research projects.
This scheme is also a way for students gain industrial experience, preparing them for employment in high value-add sectors.

Key Takeaway: The Corporate Laboratory@University is an instrumental tool to forge deep research partnerships between universities and large companies and steer researchers towards problem-based projects which can be easily applied in the industry. However these R&D centers involve large investments and involve a limited number of industry partners which makes them more suitable for a long-term research strategy to concentrate research capabilities in order to build peaks of excellence and train specialized manpower.

b. **Intermediaries for Facilitating Public-Private Partnerships**

Singapore's R&D ecosystem is quite intricate due to the presence of various research initiatives running in parallel. A coordinating body is needed for maintaining transparency on R&D activities, to generate greater interest among the private sector in public research. This will help in boosting collaborations between cross-sector players. As an example, the Biomedical Science Industry Partnership Office (BMS IPO) was set up by multiple agencies to ease collaboration.

Other countries have also recognized the importance of increasing transparency of R&D efforts. In Ireland, a central Technology Transfer Office is set up to be the main point of contact for firms looking for specific IP opportunities and research expertise. Similarly, the France Technology Transfer platform is an online tool to increase the visibility on IP developed by universities and public research institutions.

PROGRAMME HIGHLIGHT: Biomedical Science Industry Partnership Office

The vast range of research efforts and players may add difficulties as private sector players look for suitable R&D partnerships. Therefore, private sector players need an easy way to understand the offerings available in Singapore's public R&D system. They may also need help in smoothly executing their collaborations.

A*STAR, EDB, and National Medical Research Council (NMRC) have jointly set up an Industry Partnerships Office (IPO) to coordinate all the research efforts in the field of biomedical sciences. This initiative is meant to act as a coordinating body between researchers and multinationals. The IPO will also be overseeing the research needs of industry partners, encouraging them to set up their R&D functions in Singapore, facilitating collaborations with researchers, and helping in successfully executing the collaborations.

BMS IPO is able to generate cost savings by making partnerships between public and private players smoother and more efficient. By making collaborations seamless, it also contributes to higher quality research. Examples of successful public private partnerships include Bayer's Integrated Translational Clinical Network and Roche's Translational Medicine Hub, the first hub for translational medicines focusing on personalized treatments in Asia.

iv. Aligning Stakeholder Incentives to Realize Commercialization Outcomes

R&D activities stem from different motivations in public sector in comparison to those in private sector. Especially in case of investigator-led research, the researcher explores an area of interest, hoping that it would lead to breakthrough innovations. Commercial outcomes are encouraged but they may not be necessary. On the contrary, private sector players who invest heavily in R&D want to maximize their returns on research by successfully commercializing their R&D efforts. Differences in R&D drivers in the private and public sector can lead to misalignment in incentives.

This misalignment may also originate owing to the difference in R&D mandates of different government agencies. In Singapore's case, MOE administers funding for R&D activities that help improve university rankings worldwide. Since translation of research to practical applications may play a less significant role in university rankings, the funding available for academic research may place less emphasis on R&D commercialization.

Therefore, to achieve commercial outcomes from R&D efforts, stakeholder expectations need to be aligned. Singapore currently uses funding milestones to align researchers towards achieving commercialization outcomes. For instance, the National Health Innovation Centre (NHIC) offers the Innovation to Commercialization Grant. By using a phased approach, this grant requires the project to achieve certain commercialization milestones before qualifying it to the next phase. This process helps in constantly setting the right expectations of the researchers involved in a qualifying project.

PROGRAMME HIGHLIGHT: Innovation to Commercialization Grant (I2C)

There can be a misalignment of incentives between researchers and the industry partners who commercialize the research outcomes. This can lower the probability of materializing R&D activities into commercial products and services.

The Innovation to Commercialization Grant (I2C) is meant to pair a research with an industry partners who has intentions to commercialize the research outcome, maximizing the chances of successful IP commercialization. The grant has three different components with different milestones for every stage of the project:

- Innovation to Protect (I2P). Funds the IP protection of any project
- Innovation to Develop (I2D). Funds innovations with a potential commercialization plan,
- Innovation to Implement (I2I). Funds the implementation of the innovation with at least one partner. This is only applicable to those projects which have qualified for the I2D phase. This is a joint-application with the industry partner and the innovations are expected to have a proof-of-concept for this stage

The I2C grant has a 25% approval rate and is conducted in six healthcare clusters; National University Health System (NUHS), Singapore Health Services (SingHealth), Singapore General Hospital, National Healthcare Group (NHG), Eastern Health Alliance (EHA), Alexandra Health System (AHS), Jurong Health Services (JHS).

Despite all efforts, there are still many publications and research activities that do not lead to commercial outcomes because of misaligned incentives. As a result A*STAR set up an entity called Exploit Technologies Pte Ltd (ETPL). ETPL is responsible for translating the inventions of A*STAR researchers to viable solutions. It focuses on developing licensing and spin-offs from R&D activities. Singapore, therefore, still has scope for better aligning the incentives of researchers with industries, and can learn from other countries in this regard. Some universities (such as Oklahoma State University in the US) are considering to take into account the commercial track record of the faculty in the tenure process. University of Minnesota provides leave of absence to faculty members who want to help an external organization commercialize a product or service using the universities' intellectual property or know-how.

v. Supporting and Scaling Commercialization Outcomes

The commercialization process does not stop at just discovering practical applications of R&D activities, but needs further support to reach its full potential. Academic R&D can often lead to spin-off companies that are monetizing products and services produced as a result of the research activities. However, these companies often lack business expertise needed to grow their enterprises. They may also find it difficult to afford researchers who can provide them deep technical expertise to constantly innovate their product or solution. These factors may hinder the growth of such spin-off enterprises.

In order to overcome this, the GET-Up initiative was started to boost the competitiveness of local technology-intensive enterprises. This program provides technical and business advice to SMEs, and allows them to use grants to subsidize the costs involved.

On a similar note, NUS has demonstrated encouraging results in supporting and scaling research commercialization. Part of NUS Enterprise, the Industry Liaison Office (ILO) provides industry relationships to identify research areas with commercialization potential; legal and administrative support for researchers to protect and exploit their IP; as well as funding and training to start a spin-off company.

CASE STUDY: Upgrade SMEs' competitiveness through applied research

Programme: Growing Enterprises with technology Upgrade (GET-Up)

Challenge: Technology-intensive SMEs require technical assistance and guidance in order to scale their efforts and establish themselves.

Programme and Process: GET-Up is an A*STAR initiative providing a range of technology assistance schemes to SMEs so that they can increase their business competitiveness. The different schemes are:

- Technology for Enterprise Capability Upgrading (T-Up). Under this scheme, interested SMEs can apply for an expert secondment from A*STAR's research institutes, who can help the companies build their in-house R&D capabilities. Technology Innovation Program (TIP) grant can be availed to support 70 percent of the secondment costs over a period of two years.

- Operational and Technology Roadmapping (OTR). This supports the development of a technology roadmap, and can be subsidized by the SGD 5,000 Innovation Capability Voucher (ICV) offered by SPRING.

- Technical Advisor (TA). Senior researchers can be appointed as technical advisors under this scheme. These TAs can provide deep technical advice and also initiate collaborations between the company and research institutes.

Efforts and Outcomes: This programme has been launched in 2003 and has benefited over 400 companies across the electronic, infocomm, chemical, and biomedical science clusters so far. Companies have experienced average productivity gain of 20 percent, and developed greater technological capabilities. Under the T-up scheme, 480 research scientists had been seconded to 270 companies using the T-Up scheme. Based on a survey conducted by NUS-Entrepreneurship Centre, companies that participated in the GET-Up program recorded 7 percent higher sales from new products, and performed better in terms of revenue growth as well. Respondents also hired more team members to drive the new projects and experienced a 15 percent increase in employment on average. Finally, 79 percent of T-Up respondents had launched new products in the last three years, with 52 percent launching two or more new products.

Key Takeaway: The GET-Up programme has shown encouraging results applying public-funded research to SMEs in order to enhance competitiveness. However, as a Whole-of-Government approach, it is challenging to set-up and manage, and requires the constant alignment of all players involved in the schemes and grants leading to the technology enhancement.

CASE STUDY: Bridging the commercialization gap of academic applied research

Programme: Industry Liaison Office (ILO) at NUS Enterprise

Challenge: Researchers have difficulties finding industry partners to co-develop and commercialize their Intellectual Property (IP), which often takes the form of a patent. This issue arise both from researchers focusing on areas that are not easily applied to the industry and industry players being unaware of the hundreds of research projects being conducted in universities.

Programme and Process: NUS Enterprise has been established in 2001 to develop entrepreneurship among students, professors, and alumni. The ILO office has been set up in this spirit to bridge the gap between researchers and the industry and focused on two main areas; supporting researchers in protecting and exploiting their IP, and helping industry players identify commercialization opportunities.

The ILO offers various level of support:

- Administrative and legal support to protect IP such as invention disclosing, agreement forms, and patent filling. Patents filled are owned by NUS and licensing revenues are shared between the researcher (50 percent), the university department (30 percent), and NUS (20 percent)
- A one-stop solution to learn about existing research grants such as Proof of Concept, Proof of Value, and the Translational R&D and Innovation Fund
- Outreach to industry players to fund existing patents and fund applied research projects with the Technology Database of current patent filled and funded research programmes by corporations
- Workshops and incubation to support researchers in setting up their own spin-off companies with the example of the Technology Venture Lab and the LaunchPad Programme

The ILO also collaborates with other universities to create industry consortiums in which patents are pooled to concentrate the research into deeper competencies which creates a peak of research excellence.

Efforts and Outcomes: The ILO has been set up in 2002 and has been a great support to researchers since then. In 2015, the ILO's database features 210 patents which have been diligently selected among hundreds of Invention Disclosures to form a valuable pool with industry application potential of which 30 to 40 percent are licensed. This ratio is still behind those of leading foreign universities such as Stanford which can reach 60 percent commercialization, but is encouraging given the diversity of research fields covered by NUS. Current licensed patents do not generate high financial returns as the primary objective of the ILO is to facilitate knowledge dissemination rather than maximizing financial returns. However NUS Enterprise and the ILO have actively nurtured an entrepreneurial spirit among students and professors leading to over 100 companies started as NUS Enterprise's portfolio of which some have realized successful exits.
In terms of research application, NUS is a comprehensive university and conducts both basic and applied research. It is therefore harder to justify a large technology translation budget necessary to develop research into a market ready solution. A*STAR on the other hand focuses on applied research and benefits from a dedicated technology translation fund to bring research to market.

Key Takeaway: NUS Enterprise and the ILO played a crucial role in commercializing research by strengthening peaks of excellence such as the Membrane Research for Energy, Environment, Water, & Pharmaceutical Sciences and nurturing an entrepreneurship spirit leading to successful research spin-off commercialization. However a successful research commercialization requires a dynamic technology translation fund to increase the technology readiness level of the research and find industry applications.

6. Setting up a Supportive Ecosystem for Commercialization

ECOSYSTEM DEVELOPMENT					
INFRASTRUCTURE	TALENT	KNOWLEDGE EXCHANGE PLATFORMS	INTERMEDIARIES	INDUSTRY PARTNERS	FUNDERS
➢ Campus for Research Excellence and Technological Enterprise ➢ Centres of Excellence Programme (CoE) ➢ Biopolis	➢ Singapore National Research Foundation Fellowship ➢ Scholarships to develop local talent ➢ Returning Singaporean Scientists Scheme	➢ BMRC Consortia ➢ Innovation Cluster Program ➢ Global Young Scientists Summit@one-north	➢ Singapore Biomedical Sciences Industry Partnership office	➢ Vestas R&D Centre ➢ Bosh's Corporate Research and Advanced Engineering division ➢ Bio* One Fund ➢ Global Entrepreneurs Executive	➢ iJAM ➢ Technology Enterprise Commercialization Scheme ➢ Technology Incubation Scheme ➢ Early Stage Venture Fund

The efficiency of a nation to commercialize its public research is closely-dependent on having a tightly knit ecosystem that supports R&D activities and their commercialization. The Singapore government uses a top-down, multi-agency approach to attract investment, private players, talent, and to develop a supportive ecosystem for R&D.

a. **Infrastructure.** Significant resources have been invested in developing physical infrastructure that promotes collaboration. Even though Singapore is a small country, the government saw significant benefits in establishing a physical cluster that was located in close proximity to universities and research centres. The Biopolis was created to house Biomedical Science Research with a USD 500 million investment. This was meant to create a physical hub for life sciences and foster a collaborative approach between the nearby science parks, NUS, and NUH. Housing and recreation on campus were developed to attract foreign scientists. This helped in creating informal networks and building a critical mass of talent in the biomedical science sector. Singapore's seven public research institutes all have a presence in Biopolis. Current private sector tenants include GSK, Novartis, and Isis pharmaceuticals.

b. **Talent.** Attracting international talent and growing the local pool of researchers is an important factor in ensuring the success of Singapore's R&D activities. Each government agency has a different talent strategy depending on its individual mandate. EDB, for instance, leads the Industrial Postgraduate Program. This places Master's and PhD students on industry research projects, and helps in creating a pipeline of research talent for industry. A*STAR has also been implementing a series of programmes since 2001, to increase the local pool of PhD talent. As in 2014, A*STAR has attracted more than 1,000 local PhDs. MOH, through its programmes, supports and nurtures growth in the pool of

clinician scientists in Singapore. NRF Fellowship is designed to attract international talented researchers, from different countries, to perform independent research in Singapore.

c. **Knowledge Exchange Platforms.** Harnessing collaboration between the private and public sectors can lead to partnerships that facilitate the creation of commercial goods from public research. To make this collaboration possible, the ecosystem needs coordinating bodies who have an overview of the entire research landscape. There is also a need for platforms where R&D actors can exchange knowledge. The Biomedical Research Council (BMRC) initiated a consortium that funds joint projects, training, and coordinates the national efforts in translational research. Events, such as Global Young Scientists Summit@one-north brings together diverse research talent, and encourages exchange of ideas.

d. **Intermediaries.** Intermediaries are needed to facilitate cross-sector partnerships. For instance, the Biomedical Sciences Industry Partnerships Office is aware of the needs of industry players, as well as the capabilities of research institutes. It helps in making cross-sector connections to help industry players leverage public research as they develop innovative products and services.

e. **Industry Partners.** Singapore has relied on bringing in private sector investments, to speed the growth of nascent sectors, and to diversify the economy. EDB works with A*STAR in providing support to MNCs as they establish higher value-added activities in Singapore. This in turn helps in creating more attractive jobs, and further growing the body of research knowledge. In this regard, the Bio*One Fund was set up to bring in companies with new technologies and high-tech jobs to Singapore. Bio*One has 60 companies in its investment portfolio including foreign start-ups such as Fluidigm from San Francisco. Several other biotech companies have also emerged from universities.

f. **Funders.** In addition to having readily-available government funding, the Singapore government also has incentivized private sector investors to invest in R&D spin-offs. Apart from the NRF's SGD 10 million investment in Singapore-based high-tech companies through six incubators under its Early Stage Venture Funds (ESVF) Scheme, the NRF'S Technology Incubation Scheme, also sees NRF co-investing with incubators, with 85 percent funding from NRF and 15 percent from the incubator, capped at SGD 500,000. The incubators can buy their stake from NRF after three years.

A supportive ecosystem forms the bedrock of high-quality research and helps in maximizing the chances of developing innovations originating from public research.

7. Conclusion

Singapore's R&D efforts have evolved over time to account for its natural strengths. Singapore's strengths are its strategic location, world-class infrastructure, and supportive policy framework. All these factors make it a suitable location for multinational companies, interested in capturing Asian markets, to base their operations in Singapore. Singapore's high-tech manufacturing capabilities also encourage higher value-added activities. Therefore, commercializing R&D outcomes is not a choice but an imperative for Singapore to remain globally competitive.

From the launch of the first Science and Technology Plan in 1991, Singapore's R&D efforts have been dedicated towards setting the fundamental blocks for maximizing the commercialization potential of R&D activities. Prudently allocating R&D budget to areas that would benefit Singapore and the rest of the world, setting policies and incentives to attract foreign talent, investing heavily in infrastructure that can support a longer-term R&D agenda, and implementing policies and schemes to increase public-private partnerships reflect an enabling foundation for realizing economic benefits of publicly-funded research.

With a dedicated R&D strategy of only slightly over two decades, Singapore still has a potential to make more progress in its commercialization efforts. For instance, it continues to face challenges in aligning the incentives and behaviors of different stakeholders, and creating a ready pipeline of R&D outcomes that suitably meet private sector needs. Singapore presents an informative case study for countries whose governments are seeking to transition their economies via targeted public R&D and centralized ecosystem development efforts.

8. References

- "*Funds Awarded for 10 Projects Supported Under the L2 NIC First Call for Proposals*", SMU TCS iCity Lab, Retrieved June 15 2015 from http://centres.smu.edu.sg/icity/funds-awarded-10-projects-supported-l2-nic-first-call-proposals/

- "*National Innovation Challenges*", National Research Foundation, Retrieved June 15, 2015, from http://www.nrf.gov.sg/about-nrf/programmes/national-innovation-challenges

- *"New Biomedical Sciences Executive Committee established to lead Phase 2 of Singapore's Biomedical Sciences initiative",* The Agency for Science, Technology and Research (A*STAR), Retrieved June 15, 2015, from http://www.a-star.edu.sg/Media/News/Press-Releases/ID/222/New-Biomedical-Sciences-Executive-Committee-established-to-lead-Phase-2-of-Singapores-Biomedical-Sciences-initiative.aspx

- *"Singapore's Biopolis: A Success Story",* Press Release from A*STAR, YAHOO! Finance, Retrieved July 12 2015, from https://sg.finance.yahoo.com/news/singapores-biopolis-success-story-110700356.html

- *"The Biomedical Sciences Initiative",* The Agency for Science, Technology and Research (A*STAR), Retrieved June 15 2015, from http://www.a-star.edu.sg/About-A-STAR/Biomedical-Research-Council/BMS-Initiative.aspx

- *"Singapore's Biomedical Sciences R&D Effort gets Boost of S$3.7 billion",* Ministry of Health (MOH), Retrieved June 15, 2015, from https://www.moh.gov.sg/content/moh_web/home/pressRoom/pressRoomItemRelease/2010/Singapore_s_Biomedical_Sciences_R_D_Effort_gets_Boost_of_S_3_7_billion.html

- *"Biomedical Sciences (BMS) Executive Committee",* National Research Foundation, Retrieved June 15, 2015, from http://www.nrf.gov.sg/research/r-d-ecosystem/research-priorities/biomedical-sciences---translational-clinical-research/biomedical-sciences-(bms)-executive-committee

- *"The Research, Innovation and Enterprise (RIE) Landscape In Singapore",* The Agency for Science, Technology and Research (A*STAR), Retrieved June 15, 2015, from http://www.a-star.edu.sg/Media/News/Speeches/ID/1346/The-Research-Innovation-and-Enterprise-RIE-Landscape-In-Singapore.aspx

- *"Competitive Research Programme",* National Research Foundation, Retrieved June 15, 2015, from http://www.nrf.gov.sg/about-nrf/programmes/competitive-research-programme

- *"NRF Fellowship and NRF Investigatorship",* The Agency for Science, Technology and Research (A*STAR), Retrieved June 15, 2015, from http://www.nrf.gov.sg/about-nrf/programmes/nrf-fellowship-and-nrf-investigatorship

- *"Organisation: Biomedical Research Council (BMRC),* The Agency for Science, Technology and Research (A*STAR), Retrieved June 15, 2015, from http://www.a-star.edu.sg/About-A-STAR/Biomedical-Research-Council/Organisation.aspx

- Singapore National Research Foundation Fellowship (Singapore NRF Fellowship), National University of Singapore, Retrieved June 15, 2015, from http://www.nus.edu.sg/dpr/funding/NRF_RF.html

- *"The View from NTU Professors: Benefiting from PIC schemes*, Jow Lee Ying, Nayang Technology University, Retrieved July 10, 2015, from http://www.nbs.ntu.edu.sg/News_Events/In_the_Media/Pages/The_View_from_NTU_Professors_Benefiting_from_PIC_schemes.aspx

- *"Measures For Businesses",* Singapore Budget 2014, Retrieved July 12, 2015, from http://www.singaporebudget.gov.sg/budget_2014/business1.aspx

- *"Towards an advanced economy: superior skills, quality jobs, higher incomes",* Singapore Budget 2010, Retrieved July 8, 2015, from http://www.singaporebudget.gov.sg/budget_2010/download/FY2010_Flyers_for_Businesses.pdf

- *"Productivity and Innovation Credit Scheme",* Inland Revenue Authority of Singapore, Retrieved July 14, 2015, from https://www.iras.gov.sg/irashome/Schemes/Businesses/Productivity-and-Innovation-Credit-Scheme/

- *"Six Qualifying Activities under PIC",* Inland Revenue Authority of Singapore, Retrieved July 14, 2015, from https://www.iras.gov.sg/IRASHome/Schemes/Businesses/Productivity-and-Innovation-Credit-Scheme/Six-Qualifying-Activities-under-PIC/

- *"Post-Budget 2014 Survey",* Singapore Business Federation, Retrieved July 13, 015, from http://www.sbf.org.sg/images/pdf/2014/SMEC_Budget_Survey_Results_2014.pdf

- "*Biomedical Sciences Industry in Singapore: Role of EDB*" January 2014, Economic Development Board of Singapore, Retrieved June 15, 2015, from http://www.singhealthacademy.edu.sg/Documents/ProgrammesAndEvents/ASTAR%2022Jan14-(1000%20-%201030)-%20Role%20of%20EDB%20Singapore.pdf

- "*Singapore Seeks Faster Returns With Research Fund*" October 2010, Simeon Bennett, *Retrieve*d June 15, 2015, from http://www.bloomberg.com/news/articles/2010-09-30/singapore-to-set-up-1-billion-research-fund-focus-on-economic-returns

- "*The Singapore Success Story: Public-Private Alliance for Investment attraction, innovation, and export development*" April 2010, Sree Kumar, Sharon Siddique, Retrieved June 15, 2015, from https://books.google.com.sg/books?id=IVQ4UYvn-HcC&pg=PA47&lpg=PA47&dq=align+r%26d+incentives+singapore&source=bl&ots=ohSNcOT-cn&sig=q8vyGde70-y2YHiwVYi-GumSLE0&hl=en&sa=X&ved=0CEoQ6AEwCGoVChMI5rWR7LOPxgIV07e8Ch2i5wCd#v=onepage&q=align%20r%26d%20incentives%20singapore&f=false

- "*Commercialization Of Publicy Funded Research: Singapore Experience*" July 2003, Professor C C Hang, Retrieved June 15, 2015, from http://www.a-star.edu.sg/Media/News/Speeches/ID/934/Commercialization-Of-Publicy-Funded-Research-Singapore-Experience.aspx

- Land & Liveability NIC Awarded Projects for FY2014/15, Ministry of National Development, Retrieved July 10, 2015, from http://app.mnd.gov.sg/LandLiveabilityNIC/AwardedProjects.aspx

- The National Cybersecurity R&D Programme, National Research Foundation, Retried July 11, 2015, from https://rita.nrf.gov.sg/NCR

- *"16 scientists awarded Singapore NRF Fellowship",* Asia One, Retrieved July 12, 2015, from http://news.asiaone.com/News/Latest+News/Singapore/Story/A1Story20130126-398052.html

- Singapore NRF Fellowship Award (Class of 2015), Singapore Management University, Retrieved July 8, 2015, from http://research.smu.edu.sg/news/2014/01/24/singapore-national-research-foundation-nrf-fellowship-award-class-2015

- Factsheet: Land & Liveability National Innovation Challenge, Ministry of National Development, Retrieved July 14, 2015, from http://www.mnd.gov.sg/urbansustainability/2013/pdf/FactSheets_L2NIC_(for_Congress)Updated.pdf

- *"$400 million to spearhead R&D in urban sustainability",* Ministry of National Development, Retrieved July 5, 2015, from http://app.mnd.gov.sg/Newsroom/NewsPage.aspx?ID=2763&category=Press%20Release

- BCA Breakfast Talk for CEOs: Green Buildings Innovation Cluster to Bring Best Practices to Key Stakeholders, Building and Construction Authority, Retrieved July 11, 2015, from http://www.bca.gov.sg/Newsroom/pr03092014_BCA.html

- About L2 NIC, Ministry of National Development, Retrieved July 5, 2015, from http://app.mnd.gov.sg/LandLiveabilityNIC/ResearchThrusts.aspx

- Media release A*STAR deepens technology adoption for SMEs through new initiatives, A*STAR, Retrieved July 2, 2015, from http://www.a-star.edu.sg/Portals/0/media/Press%20Release/Press%20Release_ASTAR%20SME%20Day_16%20April_Final.pdf

- *"A*STAR'S GET-UP Programme Marks 10 Years of Successful Partnership With SMES"*, A*STAR, Retrieved July 2, 2015, from http://www.a-star.edu.sg/Media/News/Press-Releases/ID/1813/ASTARS-GET-UP-Programme-Marks-10-Years-of-Successful-Partnership-With-SMES.aspx

- Annual Report 2013, National University of Singapore, Retrieved July 11, 2015, from http://www.nus.edu.sg/annualreport/2013/upload/nus-annualreport-2013.pdf

- Policies Relating To University Intellectual Property, National University of Singapore, Retrieved July 14, 2015, from http://ilo.nus.edu.sg/uploads/NUS_IP_Policy.pdf

- Clancy, M. S., Moschini, G.C. (2013). Incentives for Innovation: Patents, Prizes, and Research Contracts. *Applied Economic Perspectives and Policy (2013) volume 35, number 2, pp. 206–241.*

- Wong, P. K., Ho, Y. P., Singh, A. (n.d.) *Industrial Cluster Development and Innovation in Singapore*

- Wong, P. K., Singh, A. (2011) *Public Innovation Financing Schemes in Singapore*

- Sachi, S. (n.d.) *National IP strategies for Innovation: The Singapore Experience*

- Lim, H., Wei, L. T. (2010). *Sustainable Development Impacts of Investment Incentives: A Case Study of the Pharmaceutical Industry in Singapore*

- STEP 2015: Science, Technology & Enterprise Plan 2015, *Asia's Innovation Capital*

- *Corporate Laboratory @ University Scheme*, National Research Foundation, PDF document retrieved June 10, 2015, from http://www.nrf.gov.sg/about-nrf/programmes/corporate-laboratory@university-scheme

- *Campus for Research Excellence and Technological Enterprise*, National Research Foundation, PDF document, Retrieved June 10, 2015, from http://www.nrf.gov.sg/about-nrf/programmes/create

- *Research & Development in Singapore*, National Research Foundation, PDF document retrieved June 10, 2015, from http://www.nrf.gov.sg/research/r-d-ecosystem/overview

- *National Research Foundation Annual Report 2013*, National Research Foundation. PDF document retrieved June 9, 2015, from http://www.nrf.gov.sg/media-resources/publications/nrf-annual-report-2013

- *National Research Foundation Singapore*, National Research Foundation, PDF document retrieved June 7, 2015, from http://www.nrf.gov.sg/about-nrf/national-research-foundation-singapore/corporate-profile

- Schmidt, B. (2010) *Research Funding in Singapore, Nanyang Technological University*, PDF document retrieved June 7, 2015, from http://www1.spms.ntu.edu.sg/~ccrg/WAC2010/slides/session_1/1_4_Schmidt_Singapore Funding.pdf

- *Strategic Research Programmes*, Nanyang Technological University, PDF document retrieved June 9, 2015, from http://www.ntu.edu.sg/AboutNTU/Documents/report2010_2011.pdf

- *Techventure*, Nanyang Technological University

- Ulrichsen, T., C. Commercialising university research: building multi-focus knowledge hubs and the rise of strategic partnerships, The British Council, *Global education dialogues stimulus paper*

- (2013) *Performance of SMEs in 2013: a fragile and incomplete recovery*, The European Commission

- (2013) *Commercialising Public Research New Trends and Strategies*, OECD

- (2015) *2015 Singapore's Future, Research, Innovation, and Enterprise*

- (2014) *OECD Science, Technology and Industry Outlook 2014*, OECD

- (2014) Shifting Gear: Policy Challenges for the next 50 Years, *OECD Economics Department Policy Notes*, No. 24 July 2014

- (2014) *OECD Science, Technology and Industry Outlook 2014*, OECD

- (2012) *OECD Science, Technology and Industry Outlook 2012*, OECD