

Science and Technology Trends

Fostering Startup Ecosystems

Role of Public Science in Fostering the Innovation and Startup Ecosystem in Singapore

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1. Introduction

In recent years, entrepreneurship has been increasingly regarded as an engine of growth for both developed and developing economies. In developed countries where real wages and employment have not kept pace with GDP growth, technology-based startups are seen to be crucial in creating value and jobs for the society. On the other hand, for developing economies which faced multiple societal challenges ranging from water pollution to poor sanitation, entrepreneurs are seen as potential innovators in solving social ills. According to a study commissioned by the Kauffmann Foundation, most of the new jobs from 2000 to 2010 in the US have been created by high-technology startups (Kauffman, 2012). As a city state with limited natural resources on small land area of less than 720 square kilometres, Singapore has recognised the significant role of entrepreneurship since its first encounter with the economic recession in 1985. In the 1990s, the country, as part of its economic structural reform, began to shift gear from its initial twin strategy of export promotion and foreign direct investment to that of advocating innovation and entrepreneurship, in addition to the liberalisation of

various service sectors—finance, utilities and telecommunications.

In 1999, the Singapore government through its agency, National Science and Technology Board, set up the US\$1 billion Technopreneurship Innovation Fund (TIF) to implement the new Technopreneurship 21 programme. The programme aimed to encourage entrepreneurship in technology by fostering a business climate that was conducive to investment and providing education that would inspire interest in technological innovations among students (NRF, 2016). Following the heavy losses suffered by the investment funds arising from the dot-com crash and 9-11 terrorist attacks in the early 2000s, there was limited entrepreneurial and investment activity in Singapore. To make a concerted effort to grow innovation and entrepreneurship in the city state, the Prime Minister's Office of Singapore set up a national programme, National Framework of Innovation and Enterprise (NFIE), in 2008. The objectives of NFIE were to commercialise leading-edge technologies developed by the public research institutes (PRI) and institutes of higher learning (IHL) of Singapore

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through the creation of new high-technology ventures. Since then, several schemes have been launched to attract different stakeholders to collectively build the startup community, comprising researchers, innovators, entrepreneurs, investors, incubators and accelerators.

By 2014, entrepreneurial activity has increased significantly. The prevalence rate of individuals in the working age population actively involved in start-ups, also known as the Total early-stage Entrepreneurial Activity (TEA) rate, rose from 5.7% in 2004 to above 11% in 2014, with Singapore emerging among the top five in TEA globally, after the US, Australia and Canada, according to the Global Entrepreneurship Monitor (GEM, 2016). There has also been a doubling in the number of Singapore-based startups in the technology sectors to 5,400 in 2014 from 2,800 in 2004 (SPRING, 2016). In Herrmann et al.'s (2015) worldwide study of startup ecosystems, Singapore was ranked among the top ten, moving up seven places from 2012.

This article will provide an overview of Singapore's innovation and startup ecosystem, discuss the role of the public science in the country's ecosystem strategy and its impact on economic growth. We will conclude with managerial implications and directions for future research.

2. Overview of the Ecosystem

In a recent review of startup ecosystem frameworks by the Aspen Network of Development Entrepreneurs (2013), several models were comparatively analysed along the dimensions of complexity and geographic unit of analysis. The framework used by the Babson Entrepreneurship Ecosystem Project led by Professor Daniel Isenberg was found to be more conceptual and flexible than the others, as shown in Figure 1. Drawing upon the Babson's framework (Isenberg, 2011), this section analyses Singapore's innovation and startup ecosystem.

Figure 1. Innovation and Entrepreneurship Ecosystem Framework

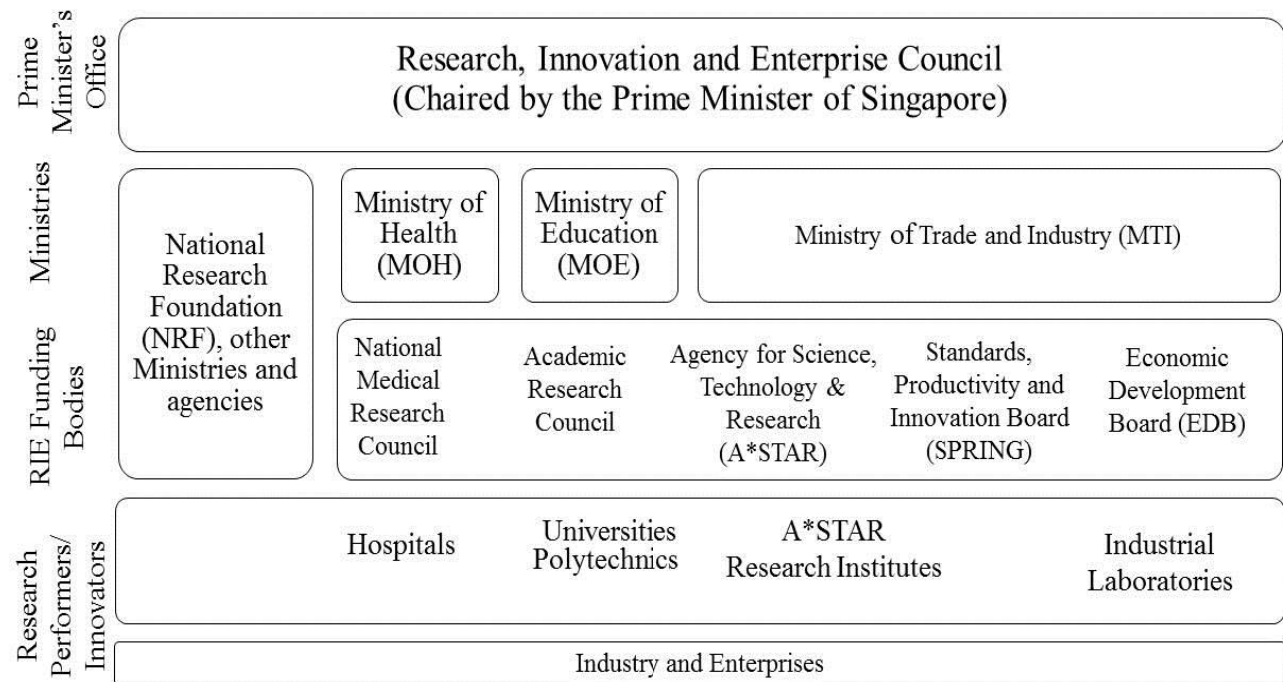


Source: Adaptation of Babson's Startup Ecosystem Framework, Isenberg (2011)

2.1. Government Policy

In 2006, the Singapore government set up the Research, Innovation and Enterprise Council (RIEC), chaired by the Prime Minister of Singapore, to advise the Singapore Cabinet on research and innovation policies, with a view to transforming Singapore into a knowledge-based society. The RIEC advocates research, innovation and enterprise (RIE) through knowledge creation initiatives such as the NFIE to drive new areas of innovation-driven economic growth. Figure 2 presents the key ministries and government agencies under the governance of RIEC that are responsible for funding a range of RIE programmes. These programmes are undertaken by research performers and innovators from the public and private research institutes, in collaboration with the business community.

To encourage risk-taking by innovators and entrepreneurs, Singapore has established venture-friendly legislation including bankruptcy laws, which have been modified since 1999 as part of Technopreneurship 21 Programme. According to Lee et al.'s study (2011) of 29 countries including Singapore over 19 years (1990-2008), there is a positive association between startup-friendly bankruptcy laws and the rate of new firm formation.

Figure 2. National Framework of Innovation and Enterprise (NFIE)

Source: NRF (2015)

In the study, Singapore's bankruptcy proceedings emerged as among the fastest (at 9.6 months versus an average of 29 months for all countries) and least costly (at 1% of debtor's estate value compared to an average of 13% for all countries), allowing bankrupt entrepreneurs to start afresh in liquidation. Reducing the duration of bankruptcy procedure down from an average of 29 months to 10 days could increase the probability of firm entry by 10 percentage points, while decreasing the cost from average of 13% to 1% of debtors' estate value could improve that by 11 percentage points.

To promote innovation and entrepreneurship, a regulatory framework of incentives including tax benefits have been put in place. For example, Singapore startups have been granted tax exemption of up to S\$200k since 2005 while angel investors have been eligible for tax deduction since 2010 of up to S\$250k for their investment in startups (IRAS, 2016). In 2016, the total tax rate of Singapore was

18.4% of profit, which was much lower than the average of OECD high-income countries at 41.2%, as provided by the World Bank. Corporate tax rate is known to have a large and statistically significant effect on new firm formation and investment. In fact, a rise in the effective corporate tax rate by 10 percentage points was found to decrease the average firm entry and investment rate by 1.4 and 2.2 percentage points, respectively, based a study of 85 countries including Singapore (Djankov et al., 2010).

Apart from venture-friendly legislation and regulatory framework, the Singapore government has set up PRI, investment institutions and financial support system to drive technology-based entrepreneurship. In particular, the Agency for Science and Technology Research (A*STAR) was established in 2002 to oversee more than 14 PRIs that conduct cutting-edge research in disciplines ranging from biomedical sciences to physical

sciences and engineering. By 2012, A*STAR has built a portfolio of more than 3,500 patents and was ranked second by the flagship journal of the Institute of Electrical and Electronics Engineers

(IEEE), Spectrum, in the Patent Power 2013 Scorecards under the category of government agency. The public investment institutions and their support schemes are listed in Table 1.

Table 1. Summary of government schemes that support innovation and entrepreneurship

Agency	Year	Name of scheme	Type of scheme	Target stakeholders	Support Quantum
SPRING	2000	SPRING Startup Enterprise Development Scheme (SEEDS)	Equity Investment	Investors	up to S\$2m (dollar-for-dollar matching) per deal
	2005	Business Angel Scheme (BAS)	Equity Investment	Business angels	up to S\$2m (dollar-for-dollar matching) per deal
	2015	Sector Specific Accelerator (SSA)	Equity Investment	Accelerators	S\$70m for the whole programme
	2008	Technology Enterprise Commercialisation Scheme (TECS)	Grant	Projects of innovators/ entrepreneurs	up to S\$250k per proof-of-concept project/ S\$500k per proof-of-value project
	2008	Young Entrepreneurs Scheme for Schools (YES!)	Grant	Schools	up to S\$10k per school (total S\$4.5m fund)
	2009	Incubator Development Programme (IDP)	Grant	Incubators or Venture accelerators	S\$30m for the whole programme in 2009 (up to 70% qualifying costs)
	2012	ACE (Action Community for Entrepreneurship) Startups Grant	Grant	First-time entrepreneurs	S\$50k (\$7 for every \$3 matching) per startup
National Research Foundation (NRF)	2008	Early-Stage Venture Fund (ESVF)	Equity Investment	Venture capital firms	S\$140 million for the whole programme
	2008	The Technology Incubation Scheme (TIS)	Equity Investment	Technology Incubators	up to S\$500k (85% of investment) per startup
	2008	Proof-of-Concept (POC)	Grant	Public research/higher education institutes	up to S\$250k per proof-of-concept project
Infocomm Development Authority (iDA)	2010	iSTART: ACE scheme (Accelerate and Catalyse Entrepreneurship)	Grant	Tech startups	up to S\$250k (50% of staff salary of 5 technical staff)

Source: Authors' compilation of scheme information from SPRING, NRF and iDA reports, press releases and websites.

2.2. Finance

While public funds are the prevalent sources of fund for the seed stage of startups, there has been a steady increase in venture capital (VC) activities in the early stages of the startups. The vibrancy may be attributed to the government-supported Early Stage Venture Fund (ESVF) and related schemes that have been introduced from 2008 (refer to Table 1) to attract VC firms to invest in early-stage startups. According to a study by the Preqin and Singapore VC Association, the number of VC deals grew from 8 in 2007 to 73 in 2013, with a corresponding increase in the aggregate deal value from USD12 million to USD454 million. During the period, VC deals in Singapore dominated the ASEAN region with an annual average of 66% of the total deal count, as shown in Figure 3.

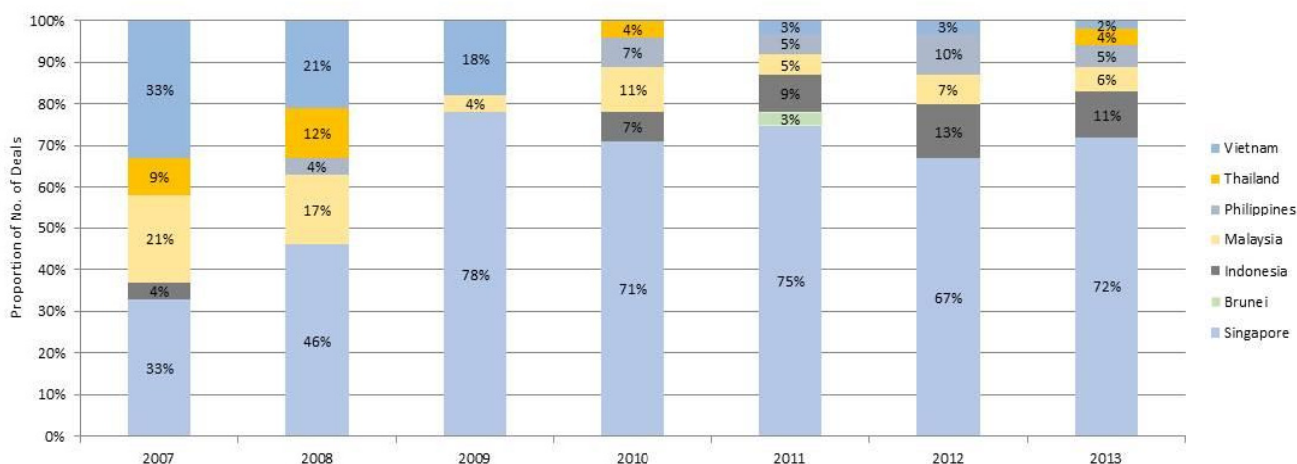
Since 2014, several banks started providing a range of loan products to startups. For example, the OCBC Bank of Singapore offered same-day approval for collateral-free loan of up to S\$100k for young startups. The loan was provided as part of SPRING's Micro Loan Programme that would charge a minimum annual interest rate of 5.5%. Although this mode of financing would not need collateral, it would require a guarantor. Other banks that provide

debt financing include DBS Bank's Micro Loan and United Overseas Bank's BizMoney.

2.3. Culture

Over the last decade, we have seen shifts in the cultural dimension of the startup ecosystem. The attitude towards entrepreneurship has become more favourable in Singapore. Comparing participants' responses in the GEM studies between 2004 and 2014, the proportion of respondents who reported that starting a business was a good career choice has increased from 49.1% to 51.7%. Those who felt that successful entrepreneurs were accorded high social status has also risen from 53.1% in 2004 to 62.9% in 2014. However, Singapore's scores for these two indicators of career choice and social status are comparable to the average of its Asia and Oceania region, at 52.3% and 59.7%, respectively, which in turn, are lower than those of the European Union region (55.6% and 68.8%) and North America (61.0 and 73.3%). It is apparent that the Asian culture is less inclined to create new ventures compared to the European and American culture. Singaporeans' fear of failure, on the other hand, remained low at around 38.6% in 2014, below the average of 42.8% across 27 countries (GEM, 2016).

Figure 3. Venture Capital Deals in ASEAN Region – Proportion by country, 2007-2014



Source: Preqin Venture Deals Analyst, 2014

2.4. Support

With strong support from the government agencies in IDP and TIS as detailed in Table 1, the Singapore ecosystem has witnessed a rapid expansion of infrastructural facilities (e.g., incubation centres, co-working space), professional services (e.g., legal, accounting, investment bankers, technical experts and advisors who work closely with accelerators) and non-government institutes (e.g., entrepreneur-friendly associations that organise hackathons and business plan competitions) set up to support innovation and entrepreneurship. Prior studies have shown that incubators providing access to physical resources, capital, network and office support could improve the survival rate of their participating ventures (Schwartz, 2013), while co-working spaces with accelerator support can promote entrepreneurship (Fuzi, 2015). By 2015, co-working spaces in Singapore have increased in number to 30, while accelerators has proliferated from one in 2010 to over 25. In response to attractive government policies, most of the accelerators came to Singapore shores in the last two years. These included international accelerators such as StartupBootCamp (founded in Copenhagen in 2010), collaboration between overseas accelerators and local companies, such as SPH Plug and Play - an accelerator operated jointly by local media firm SPH and US-based accelerator, Plug and Play, as well as local players like Lithan EdTech Accelerator and UNFRAMED. Some of the accelerators are more specialised. SPH Plug and Play, for example, specialised in media startups, while StartupBootCamp Fintech focused on financial technology.

2.5. Human Capital

Human capital is an essential resource in the ecosystem. There has been strong government emphasis on the development of R&D talent for

technological innovation. In 2014, the number of Singapore research scientists and engineers (RSE) increased by a Compound Annual Growth Rate (CAGR) of 5.7% to 32,835 from 18,935 in 2004. The number of PhD RSEs in the public sector rose by CAGR of 9.2% from 3,282 in 2004 to 7,894 in 2014, while that in the private sector grew by CAGR of 8.4% from 781 in 2004 to 1,757 in 2014 (A*STAR, 2016). Entrepreneurship training was provided in schools to foster entrepreneurial mindset since early 2000, with strong government and community support. For example, the Ministry of Education and the private sector-led ACE committed S\$15m in 2012 for schools to conduct structured programmes and internship opportunities, to equip 1,000 students with the relevant skills. While the quality of human capital is high in Singapore, the availability and costs of technical talent has been challenging for startups. Due to the small population at 5.54 million, the labour market has been tight with an annual average employment rate of 1.9% in 2015. Despite the country's open immigration policy, the shortage of human capital has been known as a bottleneck in the startup community. The time it takes to hire engineers in Singapore at 48 months is higher than that in the rest of the Asia Pacific countries (average 46 months), while the number of advisors with equity is also the highest at 1.27 mentors per startup in the region (average 0.94) (Herrmann et al., 2015).

2.6. Markets

Singapore may have a small domestic market, but its strategic geographical location at the centre of the growing markets such as India and China, its multi-cultural society and pro-business environment have made it an attractive gateway to the Southeast Asian market. Local businesses have been able to reach out to overseas customers, with US, China and Indonesia being the top target

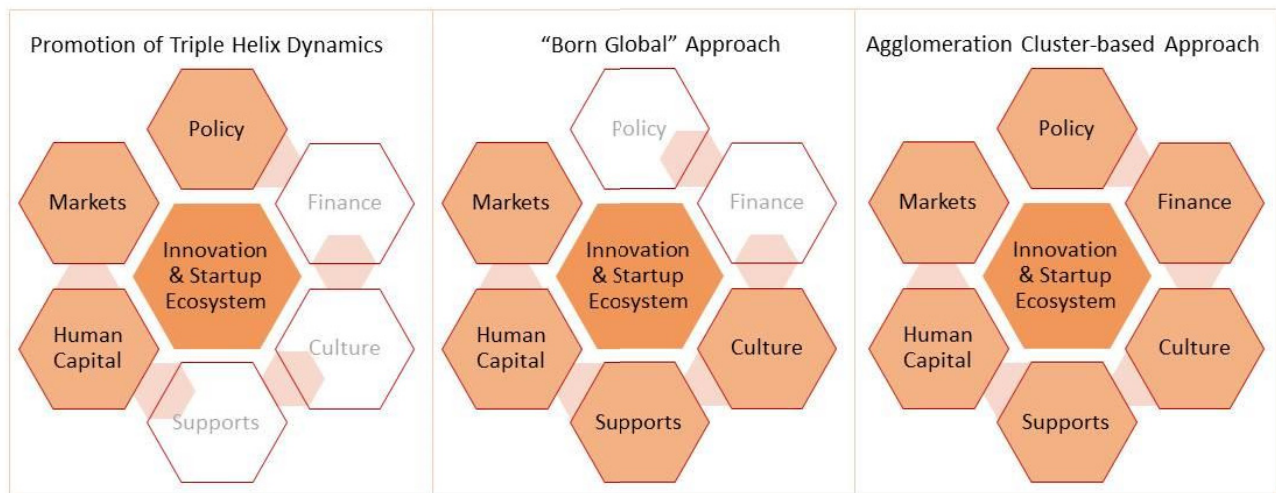
markets. More than 49% of their customers are foreign, which is higher than the average of 41% among the Asia Pacific region (Herrmann et al., 2015).

3. The Singapore Strategy

The development of innovation and entrepreneurship in Singapore is characterised by the dominant role of the city state. It can be argued that the ecosystem

owes its existence to a series of strategic choices by policymakers as the nation shifted from a traditional manufacturing economy to a knowledge-based one. This section discusses three strategic approaches that have accelerated innovative entrepreneurial activities and shaped the way the ecosystem has evolved. It highlights how the strategy develops certain aspects of Isenberg's entrepreneurial dimensions, and leverages the intersectionality of the dimensions (Figure 4).

Figure 4. The Singapore Strategy



Source: Adaptation of Babson's Startup Ecosystem Framework, Isenberg (2011)

3.1. Promotion of Triple Helix Dynamics

Etzkowitz and Leydesdorff (2000) positioned the Triple Helix model as a mechanism for describing the dynamics of institutional arrangements in national innovation systems. The basis for the Triple Helix Nexus is the interaction among three spheres— university, industry and government. Several perspectives have been explored on the emergence of the Triple Helix nexus in Singapore (Baber, 2001), highlighting how the nexus was sprung from a government platform to establish Singapore as a R&D-intensive hub.

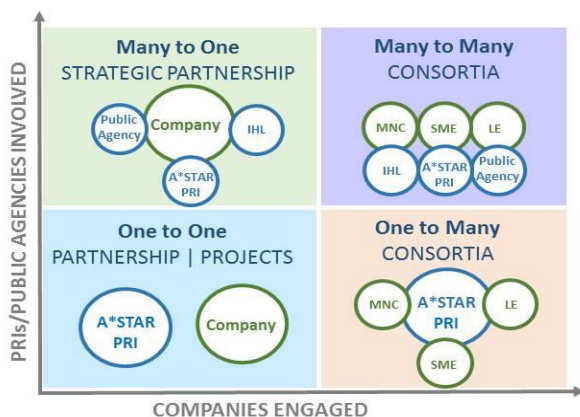
The Triple Helix approach encourages government organisations and IHLs to engage with industry, emphasising collaborative modes of interaction.

Industry involvement via technology commercialisation is also prioritised. The formation of public-private partnerships (PPP) channels R&D resources into industry-relevant areas and creates opportunities for new ideas, markets and businesses to be formed. To promote Triple Helix dynamics in Singapore, it was necessary to build a strong core of R&D capabilities in PRIs. Additionally, the government undertook to build infrastructures that support PPP projects and provide resources to bring innovations to commercialisation, corresponding to the Policy dimension of Isenberg's framework. On the part of the IHLs, the "third mission" assumed greater importance, with an industry lens being introduced

to both research and education. Leong et al. (2011) document the development of the entrepreneurial university model in Singapore's Triple Helix nexus. IHL researchers take on the role of innovators and graduates become potential entrepreneurs, corresponding to the Human Capital dimension. The PPPs created by Triple Helix dynamics foster the growth of networks, illustrating the Markets dimension.

The industry projects carried out by A*STAR highlight how Singapore has promoted Triple Helix dynamics in the ecosystem. Through unique PPP arrangements (see Figure 5), A*STAR and its PRIs have managed an extensive portfolio of projects that are highly complex and involve multiple partners and multiple levels within the government sector. The industry partners include multinational corporations (MNC), small and medium enterprises (SME) and local enterprises. The consortium projects are of special interest. These projects are field, application or industry-focused, and bring together scientists from all three Triple Helix spheres. An example is the EpiGen Consortium, which is an international alliance of the world's leading epigenetics researchers from A*STAR's Singapore's Institute for Clinical Sciences, and universities in Singapore, UK and New Zealand. In 2011, the EpiGen consortium embarked on a collaborative partnership with Nestle Research Centre and Nestle Nutrition.

Figure 5. Configuration of A*STAR industry projects



Source: A*STAR (reproduced with permission)

The Triple Helix approach also forms the basis for several initiatives undertaken to implement broader strategies for ecosystem development, which will be discussed in the following two subsections.

3.2. “Born Global” Approach

Singapore's small domestic market necessitates a global outlook for growth-stage start-ups. This limitation extends beyond access to distribution channels to issues of resource acquisition. In a study on Singapore high-tech startups by Wong et al. (2011), the fastest-growing startups revealed that the top challenges include recruitment of talent and the need to diversify their customer bases. While internationalisation is the answer, the cost of expansion is another frequently cited concern.

The internationalisation impetus for startups is recognised by policy makers, corresponding to the Policy dimension in Isenberg's framework. In the 2016 government budget, internationalisation is a key pillar for policies to assist startups to scale up. Two government agencies, SPRING and IE Singapore, have been providing internalisation assistance to Singapore startups in terms of establishing contacts and exploring markets abroad, supporting the expansion of the Markets dimension. Moving forward, the focus is on scaling up through digital internationalisation by building startups' capabilities in areas such as customer analytics and social media marketing. Startups with these capabilities are “born global” and can take advantage of the international digital economy to participate in global markets. To implement capability development strategies, government agencies work with industry associations and entrepreneurship facilitators such as accelerators and incubators, drawing on the Supports dimension.

The concept of “Born Global” also encompasses

inward-flowing talents and ideas, as the presence of overseas entrepreneurs and startups enriches the networks in the local ecosystem, further influencing the Markets dimension. Additionally, a more global outlook and the interactions between local and foreign entrepreneurs strengthen the Culture dimension. International exposure can mitigate the conservative attitudes towards entrepreneurship in Singapore society which has been documented in the GEM project.

A unique initiative that illustrates the Born Global approach is the National University of Singapore Research Institute (NUSRI) located in Suzhou Industrial Park, China. Founded in 2010, NUSRI facilitates cooperation between China and Singapore in research, education and enterprise activities. Drawing on Triple Helix dynamics, NUSRI provides a launchpad for Singapore and international startups to access the Chinese market. The NUSRI Incubator hosts over 15 Singapore startups on site, providing incubation services and networking opportunities with Chinese entrepreneurs, VCs and government officials. NUSRI also acts as a conduit for Chinese startups that are reciprocally attempting to enter the Singapore and ASEAN markets.

The Diagnostics Development (DxD) Hub also provides a platform for globalisation of Singapore startups. Led by A*STAR and launched in 2014, the DxD Hub brings together multiple stakeholders in Singapore's MedTech sector onto a common borderless platform to fast-track the development and commercialisation of diagnostic solutions. It integrates expertise across various segments of the industry by nurturing partnerships with and among companies, researchers, clinicians and regulators. The unique feature of the Hub is the early involvement of clinicians in the product development process, made possible by collaborations with hospitals, medical and clinical research centres. Through DxD Hub, startups and

SMEs can access such public sector intellectual property (IP) that may otherwise be beyond their search scope. They can tap on the capabilities of larger industry players, including the many global MedTech companies in Singapore, to develop market-ready products that meet international regulatory standards.

To promote a "Born Global" mindset, policies have also been implemented to attract foreign entrepreneurs to start and operate new businesses in Singapore. The Entrepass (Singapore Entrepreneur Pass) scheme was launched in 2004, targeted at entrepreneurs with innovative business ideas. Assessment is based on merit and emphasises innovation content and growth potential. In 2011, NRF proposed a Global Entrepreneurial Executives scheme which aimed to attract entrepreneurs who have run high-growth companies in selected high-tech sectors to relocate their companies to Singapore. The entrepreneurs would contribute to the local ecosystem by providing guidance, mentorship and inspiration to local startups. Apart from these entrepreneur-specific initiatives, the talent augmentation policy and attractive tax structures have also been a magnet for innovators to come to Singapore.

A leading example of a foreign entrepreneur who has made significant contributions to the local scene is Eduardo Saverin, a Facebook co-founder. Since moving to Singapore in 2009, he has made several high-profile investments in local startups, including the online grocer Redmart and property portal 99.co. Roger Egan and Vikram Rupani, both non-Singaporeans with substantial corporate experience, met at the INSEAD Asia Campus in Singapore and decided to launch their startup, Redmart, here in 2011. Today, Redmart is one of the fastest growing e-commerce companies in Singapore, with regional expansion plans and jobs for several hundred employees.

3.3. Agglomeration Cluster-based Approach

The centrepiece of Singapore's strategy to accelerate the growth of the innovation and entrepreneurship ecosystem is the cluster-based approach. The building blocks of this approach are the agglomeration economies that arise when firms and people locate together. Contemporary theories on the economics of agglomeration have stressed the role of innovation and knowledge flows (Maskell, 2001), ideas explored in studies of dynamic entrepreneurial areas like the Silicon Valley. The Singapore experience presents a case of planned agglomeration to create an entrepreneurial cluster, with knowledge flows as the key mechanism for cluster development, and innovation and enterprise as the rents of agglomeration.

The cluster-based approach develops all six dimensions of Isenberg's framework. In describing industrial cluster development in Singapore, Wong et al. (2010) spell out five components which must be put in place for a knowledge cluster to be created:

- 1) Establishment of public science infrastructure, that is, universities and PRIs (Policy and Human Capital dimensions)
- 2) Attracting private sector to the cluster, including both the knowledge-intensive firms that form the core of the cluster and the supporting services that will surround them (Markets dimension). In the entrepreneurship cluster context, a key component of private sector supporting services are the investment firms (Finance dimension).
- 3) Establishing linkages with lead user markets (Markets dimension).
- 4) Facilitating knowledge flows and network links. This will include inter-sector networks, as well as creating platforms and mechanisms

for collaborations (Supports dimension) and building social networks and communities of shared interest (Culture dimension).

- 5) Establishing a business environment and regulatory framework for the cluster to function. This will involve regulations and incentives (Policy dimension), infrastructure (Supports dimension) and resources (Finance dimension)

The cluster-based approach for ecosystem development is exemplified by the JTC Launchpad @ one-north project. The Launchpad was started in 2011 on the principle of co-locating all the key actors in the local technologically-based entrepreneurship scene in one space, conferring collective visibility on the community. The Launchpad kicked off with a single dilapidated building dating from the 1970s, Block 71 (Blk71) in the Ayer Rajah Industrial estate. In 2010, Blk71 was slated for demolition. In 2011, NUS Enterprise (a division of NUS that promotes innovation and entrepreneurship), Singtel Innov8 (the venture investing arm of telecommunications company Singtel) and the Media Development Authority of Singapore developed a collaboration to turn Blk71 into a central hub for tech startup activities. This illustrates a Triple Helix nexus strategy (Policy, Human Capital, Markets dimensions). The Blk71 initiative concentrated startups, investors (Finance) and facilitating organisations such as incubators and accelerators (Supports) in one space, to realise localisation economies. Regular networking events and an open-all-hours philosophy created a community where sharing and learning take place organically (Human Capital and Culture). Blk71 expanded rapidly with high take-up rates, and demand soon exceeded supply. In response, the government expanded the project to include Blk73 and Blk79, and

Launchpad @ one-north was officially launched.

In 2013, The Economist reported that the Launchpad was the highest-density hub of tech startups in the world. As at Nov 2015, it was estimated that the Launchpad was home to 21 VC firms, 19 accelerators and incubators, 13 facilitators such as industry associations and government agencies, and 220 resident startups, with dozens more in co-working spaces or incubation facilities. The situation is also dynamic as there is high frequency of new startups entering the Launchpad, and incumbent startups leaving as they grow and require more space.

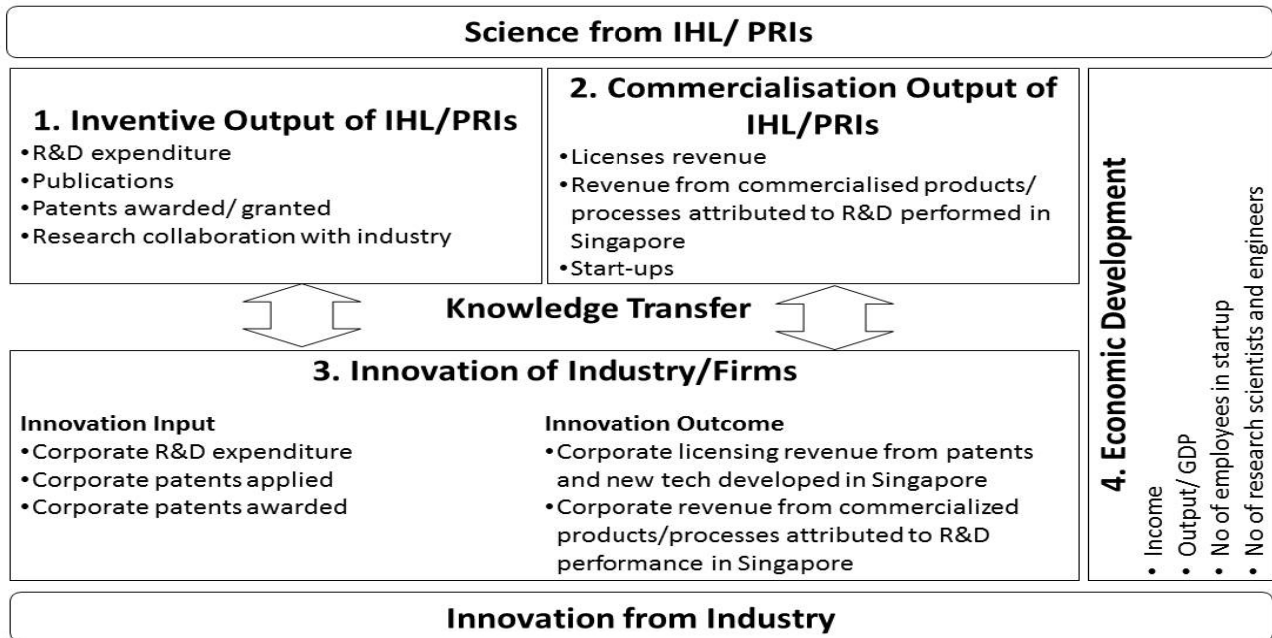
The physical location of the Launchpad is an important factor. The one-north district is adjacent to the Singapore Science Park, the Biopolis and Fusionopolis precincts. The Launchpad is across the road from several A*STAR PRIs and SPRING Singapore, the government agency that oversees promotion of entrepreneurship. The Launchpad houses incubation facilities by the two largest local universities – NUS Enterprise Incubator and NTUitive. The Launchpad is also home to A*StartCentral, an initiative by A*STAR that supports technopreneurial ventures by providing both hardware (e.g., engineering and life sciences facilities, equipment) and software (e.g., mentorship) assistance. Being the only life science infrastructure in Singapore, A*StartCentral takes a borderless approach in being accessible to innovations. The open-innovation engineering and life sciences community of A*StartCentral has also engaged partnerships with strategic investors looking at scaling up early-stage investments regionally. The concentration of public science and top-notch research talents in and near the Launchpad has not only produced innovations but also attracted large tech-based corporations to the area. These are the lead users for many startups, providing partnership opportunities and potential customer bases.

4. Impact

Given the hefty investment in executing Singapore's strategy to build the innovation and entrepreneurship ecosystem for the past decade, it is important to examine the impact it has made on the economy. A review of the innovation impact literature shows that there is no lack of studies on impact indicators and methods, with most focusing on single indicators such as patents or publications. However, policymakers are generally aware that the journey from investing in IHL/PRI to do public research and innovation through making an impact on the industry and economy is a long and tortuous one involving multiple stages with distinct stakeholders and risks at each stage. While indicators such as publications and patents are useful to demonstrate the inventive output of IHL/PRI, they do not show if and how the underlying knowledge of the patents eventually become commercialised into new product sales by the industry. It is therefore generally acknowledged that there is no single indicator that can present a complete picture of the economic impact of public science on the innovation and startup ecosystem. For holistic impact assessment, the RIE Impact Measurement framework is used in A*STAR, which considers the complex nature of the RIE value chain, to measure intermediate output and outcome at four different stages. The stages are (a) inventive output of IHL/PRI, (b) commercialisation output of IHL/PRI, (c) innovation of industry/ firms and (d) economic development, as highlighted in Cheah and Yu (2016). Figure 6 provides a summary of the framework and the indicators that are typically used by public and business policymakers to measure impact at each stage.

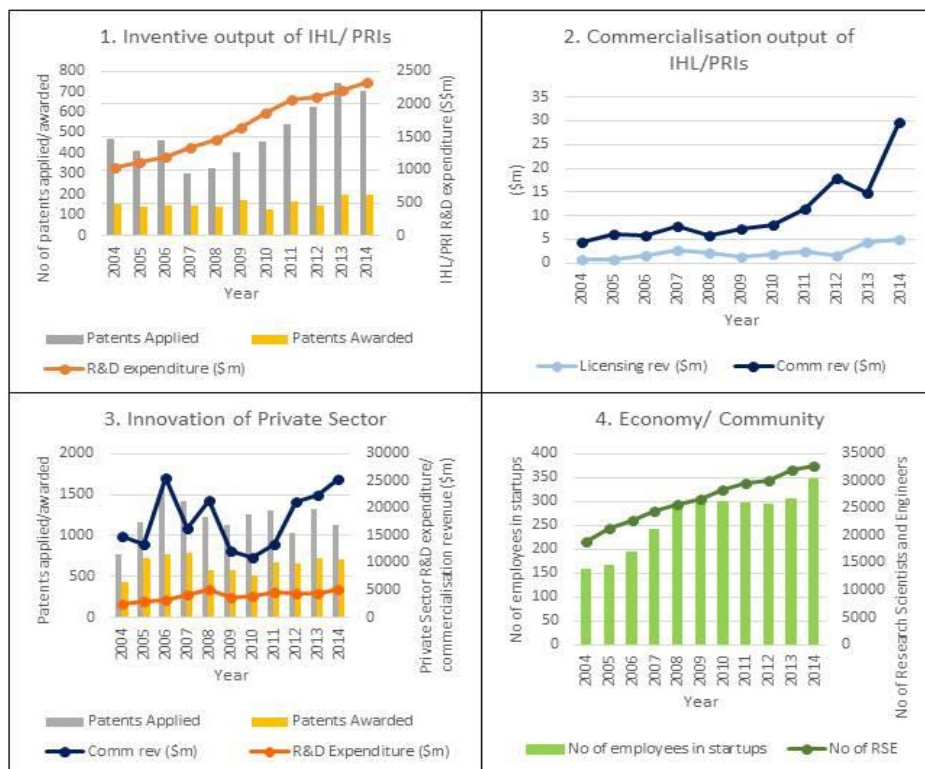
Applying the framework in Singapore's innovation and startup ecosystem, we have made several observations about the impact of public science at each of the four stages of Singapore's RIE value chain, as presented in Figure 7.

Figure 6. RIE Impact Measurement Framework



Source: Cheah and Yu (2016)

Figure 7. Results of RIE's journey



Source: A*STAR Annual National Surveys of R&D, 2004-2014 (A*STAR, 2016)

4.1. Inventive output of IHL/PRIs

R&D expenditures, patents applied and patents awarded are typically used to assess the inventive output of IHL/PRIs. In Figure 7, Chart 1 shows that, for the past decade, there has been a consistent increase of R&D expenditures from S\$1,029.73m in 2004 to S\$2,338.71m in 2014, with a corresponding rise in patent applications and awards from 469 and 156 to 707 and 196, respectively. In the same period, the number of tech-based startups grew from 2,800 to 5,400 (SPRING, 2016). While we acknowledge that early-stage technologies have higher level of uncertainty than those of later stage, the upside of the former is greater than that of the latter. It is evident that good science is crucial in the innovation and startup ecosystem as it provides strong technological knowledge/IP base for enterprises that can be potentially game-changing. The public sector therefore plays an important role in investing in the inventive output of universities/PRIs, especially in technology domains that are strategic to the country's wellbeing but require longer investment horizons than what can be accepted by the private sector.

4.2. Commercialisation output of IHL/PRIs

The commercialisation output of IHL/PRIs has seen a healthy trend from 2004 to 2014, as shown in Figure 7 Chart 2. The revenues that these institutions receive from licensing their IPs to companies have increased from S\$0.84m to S\$4.99m, while the revenue from commercialised products and processes attributed to R&D performed in Singapore grew from S\$4.45m to S\$29.76m. For the past decade, we see a closer alignment between research directions and industry needs, and corresponding increase in the commercialisation output of universities/PRIs. While there is an increase in tech-based startups during the same period, studies have shown that 50% of new businesses ceased operation by their fifth year in Singapore. Although

a similar trend is observed in the US, the technology transfer organisations could play a bigger role in helping startups de-risk their commercialisation of public-funded R&D through gap-funding to raise the readiness levels of their technologies to meet industrial requirements.

4.3. Innovation of Industry/Firms

In the private sector, we see a positive trend of innovation input by the firms, as illustrated in the Chart 3 of Figure 7. R&D expenditures have increased from S\$2,589.99m in 2004 to S\$5,215.66m in 2014, and patent applications and awards grew from 777 and 433 to 1,131 and 707, respectively. A corresponding increase is seen in the innovation outcome of the firms in the same period, which reported steady growth from S\$202.33m and S\$14,925.22m to S\$465.71m and S\$25,207.55m for their licensing revenues from patents and new technologies developed in Singapore, and revenues from commercialised products and processes attributed to R&D performed in Singapore, respectively. While there is overall growth in both innovation input and outcome of the firms, the private sector-led R&D (ranges on average between 1.2% and 1.8% of GDP) still has much room for improvement, compared to the OECD average of almost 2.5% of GDP (OECD 2013). There is therefore a strong need to continue building the technological and business capabilities of local firms through education and triple helix networks.

4.4. Economic Development

The indicators that are typically used to measure impact on the community or economy are human capital and employment created by the startups from 2004 to 2014. During this period, the startup share of Singapore employment has increased from 7.1% (156,500 employees) to 9.5% (345,400), while the number of RSEs has grown from 18,935 to 32,835. It is evident from the Chart 4 of Figure 7 that the

startups in both tech and non-tech sectors have created employment for the local workforce. There is, however, a lack of data on their contribution to output, national income and GDP. Given the importance of startups, such data as well as those on firm's innovation outcome (e.g., no of new products, new product sales) should be collected, tracked, benchmarked and analysed to facilitate continuous enhancement of policy tools in supporting the startups.

4.5. Case Studies

The case studies presented in this section illustrate the success of Singapore's strategic approaches for innovation and entrepreneurship promotion.

One of the earliest A*STAR PPP consortia is the Aerospace Programme which was started in 2007. It is an example of a Many-to-Many collaboration structure which interfaces eight PRIs under the Science & Engineering Research Council (SERC) umbrella with an industry consortium comprising leading aerospace Original Equipment Manufacturers (OEM) and Singapore aerospace companies. Consortium projects are pre-competitive in nature and driven by industry needs. Via this programme, aerospace companies work bilaterally with A*STAR on commissioned or collaborative research. One member of the consortium is Rolls Royce, which has been present in Singapore since the 1950s and now contributes over 15% of the nation's aerospace output, with a local workforce of over 2,400 people. The company signed its first collaborative agreement with A*STAR in 2004 and the relationship has flourished since then. Rolls Royce has set up a joint Surface Finishing Lab together with A*STAR's Singapore Institute of Manufacturing Technology (SIMTech). Over 75 collaborative projects have been jointly undertaken by Rolls Royce and SIMTech.

A resounding success story emerging from the DxD Hub is InvitroCue, a company providing

bioanalytic services using cell-based model and imaging algorithm. The technology originated from A*STAR, and was further developed and validated through collaboration with pharmaceutical companies, leading pathologists and research scientists from universities and PRIs. Co-founded by experienced serial entrepreneur, Dr Steven Fang, InvitroCue was established in 2012 as an A*STAR spinoff. In its early stages, it was supported through A*STAR's gap funding. The company was an early partner of the DxD Hub upon the platform's launch in 2014. Just two years later, in January 2016, InvitroCue was publicly listed on the Australian Securities Exchange. With market capitalisation valued at S\$40 million, the company has doubled its sales growth in two years since 2014. Its marketing strategy was to sell its customised cell-based assay models to global pharmaceutical companies through collaborative partnerships and service-based contracts. The revenues secured through this strategy were used to support the development of the digital pathology service, which has been successfully deployed in global pharmaceutical companies and hospitals. This "born global" foresight was facilitated by the DxD Hub and the Triple Helix networks in Singapore's ecosystem.

Visenze is an active member of the Launchpad @ one-north community. The startup offers a machine-learning visual search and recognition solution that sprung from deep research conducted at the NUS-Tsinghua Extreme Search Centre. After being spun off from NUS in 2012, Visenze was first incubated on campus before moving to Blk71 in 2013. There, the company leveraged Singapore ecosystem's infrastructure. It received support from IE Singapore for internationalisation and from SPRING's Technology Enterprise Commercialisation Scheme, which was helpful as the founders bootstrapped and piloted their prototype to overseas customers, such as Rakuten in Taiwan. Today, leading e-commerce companies such as Zalora,

Flipkart, Lazada, Reebonz and Rakuten are using Visenze's technology in markets around the world. The company has won numerous local and global awards. It was lauded as the Most Promising Startup at the 2015 Emerging Enterprise Awards in Singapore, and won the Gold Award at the ASEAN ICT (Infocomm Technology) Awards 2015. While at the Launchpad, Visenze secured Series A funding. After graduating from the Launchpad, Visenze has moved to the nearby Blk67 and continues to contribute to the Launchpad community.

5. Conclusion

We presented three strategic approaches that have been pursued in Singapore. First, the innovation and startup ecosystem is anchored by Triple Helix dynamics. Within this nexus, public science and strong support from policy makers in promoting public-private-partnerships have been crucial. Closer links with industry align the public science agenda closer to commercial demands. Second, the strength of Triple Helix dynamics is the foundation for Singapore's strategy to create startups that are "born global". Leveraging the collaborative networks between these different actors, initiatives such as the DxD Hub and NUSRI Suzhou could be successfully implemented. Local tech startups are able to access foreign markets either through a physical launchpad as in the case of the NUSRI Incubator, or through virtual connections as in the case of the DxD Hub. Finally, the Launchpad @one-north project illustrates the planned agglomeration strategy to create an entrepreneurial cluster in Singapore. By co-locating all key stakeholders in the ecosystem within the same geographic location, the Launchpad has within three years gone from a half-abandoned site to the highest-density tech hub in the world. Triple Helix dynamics and public science have been essential in the Launchpad's achievements. A*STAR and the

two largest local IHLs are prominently present, supporting dozens of startups at any given time.

We put forth four key messages from our examination of impact measures. First, it is evident that good science is crucial in Singapore's innovation and startup ecosystem. Given the vulnerabilities of Singapore as a small nation, strategic technology domains have been carefully identified for competitive advantage. The public sector plays an especially important role in the inventive output of IHLs/PRI in these technology domains that would require longer investment horizons than are acceptable to the private sector. Second, there is a gap between the readiness levels of public science output and industry needs. The technology transfer organisations of IHL/PRI could play a bigger role by providing gap funding to raise the readiness level of their technologies and help startups to de-risk the commercialisation of public-funded R&D. Third, there appears to be a relative deficit of technological and business capabilities among local firms which limit their absorptive capacity and innovation levels. There is a strong need to build capabilities through education and triple helix networks. Lastly, a thorough assessment of the ecosystem is hampered by a lack of data on the economic contribution of startups in terms of output, value added and innovation outcome. A measurement and data collection framework that is standardised across local and international research, innovation and enterprise promotion agencies should be implemented to systematically track such data so as to facilitate analysis, benchmarking and continuous improvement of policy tools in supporting startups.

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