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The university-innovation nexus in Singapore

June 2012

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Executive summary

Singapore is a small but successful country with few natural resources and has had to build on its location, the innate abilities of its population, strong social cohesion and its low sovereign risk to drive economic growth. It has capitalised on its few natural advantages by providing a business friendly environment, negotiating free trade agreements and investing heavily in education and research. This holistic approach to creating an innovation system has helped develop indigenous business and attract inward investment from multinational corporations, many of which have established research and development facilities. Singapore ranks highly in global indexes of innovation and business competitiveness.

The State takes an active and high profile role in marketing (including to overseas business) the country's education, research and workforce capabilities and extensively promotes the country's broader business support programs and the benefits they provide. The importance of education, universities and research in supporting economic development seems embedded in the national culture, finds a high degree of acceptance and is reinforced by the nation's five year national technology plans, the most recent of which is *Research Innovation Enterprise 2015*. This allocates S$16.1 billion (US12.5 billion) over 2011-15, sets aside 70 per cent of public research funding for economic development and sets a gross expenditure on research and development target of 3.5 per cent GDP.

Singapore has recognised the importance of science and technology as drivers of economic development ever since its creation as an independent nation. The national policy framework has also built on the importance of tertiary education institutes as sources of expertise that the business sector can draw on, as well as their important roles as performers of research and as the suppliers of a highly skilled and capable workforce. The nation's innovation system has developed considerably since 1965 and in 2009 there were 11 higher education organisations, 27 government and 20 public research institutes, as well as 854 private sector organisations all conducting research. The education and research systems are complementary, interactive, and mutually supportive with a high degree of specialisation across the system.

Singapore has both publicly funded (autonomous) universities and private universities, some of which are highly specialised, focused on narrow discipline areas or areas of business need and some of which cater specifically for people already in the workforce. The polytechnics train the middle level professionals needed to support the nation's technological and economic development, while the Singapore Institute of Technology provides industry-focused university education for polytechnic graduates. Polytechnics perform research, including research aiming to convert inventions resulting from intellectual breakthroughs in universities to practical propositions for industry. The clearly defined and differentiated missions of the various higher education institutes result from and promote further innovation, specialisation and responsiveness to business and community needs.

The research funding bodies recognise the need for new knowledge to provide the foundation for future innovations and that quality postgraduate training is necessary to provide the talent needed by the economy and academia. There are schemes to support academic entrepreneurship across all stages of the innovation chain and to support collaboration between the different sectors at the institutional as well as national level. In addition to specific policies and programs, Singapore has explicitly used co-location to facilitate collaboration and cooperation between the sectors, building facilities in close proximity to each other and encouraging the sharing of buildings.

Introduction

Singapore, like Australia, is one of the world's most prosperous countries. However, the basis for Singapore's prosperity is quite different from that of Australia's and for this reason it provides an interesting and complementary case study.

While much of Australia's current affluence flows from its rich endowment of mineral resources, Singapore's success builds on its geographical position, strong trading links and the innovative and entrepreneurial outlook of its government. Whereas Australia's exports are mainly mineral and agricultural commodities, machinery, transport equipment and services such as education and tourism, Singapore exports consumer electronics, IT products, pharmaceuticals and (increasingly) financial services.

With an area of 697 sq km, Singapore has a very much smaller land area than Australia's 7.7 million sq km, although at 4.7 million its population is almost 22 per cent of Australia's 22 million. Singapore's education expenditures at 3 per cent of GDP rank it at 131 in the world, compared to Australia's world ranking of 81 based on expenditures amounting to 4.5 per cent of GDP. With a per capita GDP of $59 900 (in ppp terms), Singapore ranks number 5 in the world, compared to Australia's 18th position.[1]

Within Australia 3.6 per cent of the workforce is in the agricultural sector, 21.1 per cent in manufacturing and 75 per cent in the services sector. Given Singapore's small land mass and high population density, it is not surprising that the agricultural sector accounts for only 0.1 per cent of employment, while manufacturing accounts for 30.2 per cent and the services sector 69.7 per cent.

One consequence of Singapore's relative lack of natural resources (it even has to import drinking water) is that it has had to concentrate on the innate abilities of its population to stimulate economic growth and development. The qualities of its people, its stable political situation and the advantages of its geographical location have all played important roles in attracting foreign investment and the companies that bring with them advanced technologies and world class expertise.

Directly seeking inward investment has been important but the success of this approach has been dependent on making Singapore an appropriate place to invest. This has required building on natural advantages through the development of world class infrastructure (including a highly educated population) and providing a business friendly environment in terms of regulation, ensuring stable economic conditions, the negotiation of free trade agreements, and so on. The government has used its investments in education, research and the promotion of research, science and technology to support the attraction and development of industry (and the attraction of industry research facilities). In doing this the government has had the advantage of being able to operate strategically and over the long term, without the perturbations that can arise from short term political change and changing priorities.

An explicit aim of government policy has been to make Singapore a 'Global Innovation Hub' as 'Asia's innovation capital'. This aim builds on a whole of government approach and top down leadership. As one example, the nation's prime minister chairs the Research, Innovation and Enterprise Council which has developed a national framework to grow innovation and enterprise.[2] In addition, five year National Science and Technology Plans provide clear strategic directions and the government presents strong, ongoing policy signals linked to effective accountability mechanisms, with ministerial-level steering committees driving development in key areas.

1 www.cia.gov/library/publications/the-world-factbook/index.html

2 www.nrf.gov.sg/nrf/councilBoard.aspx?id=160

Singapore's high ranking in the INSEAD Global Innovation Index 2011 provides a clear indication of the success the nation has achieved in developing and drawing on the skills and intellectual resources of its population and in creating an environment conducive to the attraction and further development of high technology industries.[3] Overall, this index ranks Singapore third in the world and gives Singapore top ranking for both its business sophistication (which encompasses knowledge workers, innovation linkages and knowledge absorption) and the human capital and research subcomponents, with second ranking for market sophistication. For comparison, Australia's overall ranking was 21 and its business sophistication position 17. While the Global Innovation Index places Australia (at 23) ahead of Singapore (at 31) in terms of knowledge creation, the knowledge diffusion ranking places Singapore second in the world compared to Australia at 70. Together these sets of data suggest that in Singapore business may have a better understanding of the benefits it can achieve from working with universities and a greater propensity to do so.

The purpose of this paper is to explore the role that universities have played in promoting Singapore's economic development and in particular to examine the importance of university business interactions in promoting the flow of information, ideas and technology.

3 www.globalinnovationindex.org/gii

The Singapore innovation system

There are many ways of describing a national innovation system. One is to consider the roles, responsibilities and networks of the various bodies responsible for funding, performing and using research in the context of the government policies, programs and institutions that support innovation. While the focus of this paper is on universities, the development of Singapore's innovation system has been holistic, such that the relationships between the differentiated elements of the system are more explicit than they are in some other countries. In particular, the development and differentiation of Singapore's universities has reflected the need for specialisation within the broader system to meet the economic demands of a rapidly developing country. This has often involved specific actions to attract and seek expertise from overseas, for teaching and access to curriculum material, as well as for research. The private universities and the joint developments between public universities in Singapore and prestigious universities in other countries, particularly the US, provide a clear demonstration of this entrepreneurial approach.

Funding for research and innovation comes from business and a wide range of government programs, outlined later in this paper. This funding flows to business and to Singapore's public research and development performing bodies, which fall into four categories. First are the universities and polytechnics. Then there are the research institutes that fall under the auspices of the Agency for Science, Technology and Research and its two research councils. In the third category are a number of hospital and public institutes performing medical research. And fourth are the Defence Science Organisation's national laboratories which perform military research. All of these, to a varying extent and for different purposes, interact closely with the business sector, which employs almost 60 per cent of the nation's researchers. Data provided in the Yearbook of Statistics Singapore 2011 show that in 2009 there were 854 private sector organisations performing research, 11 higher education organisations, 27 government and 20 public research institutes.

The relationships between these different bodies and business are multifaceted and complex. For example, the clear distinction between polytechnics and universities means that the former often play an important and explicit role in developing for commercialisation inventions made originally by the universities. Similarly, the research institutes are clearly seen to complement rather than duplicate the role of universities in the kind of research they perform and the outcomes they aim to achieve. Among other benefits, this role clarity and differentiation can facilitate a more focused and nuanced relationship between business and the other players in the innovation system than is sometimes possible in other systems. Providing an historical perspective on the development of these institutes can help make this clear. In considering the development of Singapore's innovation system it is convenient to examine first the government institutions that set the policy framework for its operation and which deliver the programs that help support and direct its operations. This can lead into a description of its post-secondary education system and a fuller description of the bodies which fund and perform research.

Some history[4]

Singapore's development exemplifies the way in which industrial development and the expansion of public research capabilities and effort can work hand in hand, one complementing the other. The policy relationship between economic progress and research investment has been explicit and can be seen not just in national policies but also in the institutional arrangements established to develop and implement these policies.

4 Information in this section comes largely from www.a-star.edu.sg/Portals/0/aboutastar/2012_Commemorative_Pub_Webv6.pdf which commemorates the first 20 years of A*STAR.

Singapore did not come into existence as a separate nation until 1965 but the government had already established a Science Council as early as 1967. This coordinated a modest research budget that was measured in tens of thousands of dollars.[5] However, in 1970 a survey of research and development activities in the public sector recommended that the government attract foreign, science-based industries to set up in Singapore and this set the context for broader policy development.

Among other activities, the Science Council ran an Applied Research Fellowship Scheme to award part-time study fellowships to graduate scientists and technologists in industry; and a Research Grant Scheme intended for researchers in tertiary institutions. Modifications to the schemes made in 1975 noted that the Research Grant Scheme should fund projects that were more applied in nature "since they arise from government ministries interested in using the results". This emphasis on research for impact has been an ongoing theme – but not at the expense of support for basic research.

One indication that the government recognised the broad support that universities can provide to business was that in 1973 Singapore established an Applied Research Corporation (ARC) to offer small and medium enterprises (SMEs) a wide range of services, with the Corporation drawing on the expertise available in Singapore's tertiary education institutions to provide its services. In effect the ARC acted as an intermediary body, facilitating the access of SMEs to university expertise. The responsibilities of the ARC acknowledged that university expertise across all areas was important to business – the focus was not a narrow one on science and technology research but covered economic science, business management and engineering systems as well as industrial research and development.

From the late 1970s Singapore's Economic Development Board (EDB) introduced programs to attract pioneering high-technology companies to invest in Singapore. A section for Advanced Technology/R&D in the EDB successfully encouraged SMEs to invest in research to raise the quality of their products; and persuaded multinational corporations to establish research and development facilities in the country. These initiatives helped to create potential partners for university and other researchers as well as employment opportunities for graduates and postgraduates. One measure of their success is that by 2012 Singapore was home to over 100 global biomedical science companies, including many leading multinational corporations.[6]

In 1989 it became apparent that:

> *[Singapore] required a capability and capacity for knowledge creation and innovation to translate the new knowledge for the marketplace. Having a growing pool of researchers and a credible research capability ..., both in the private and public sector, was therefore crucial to fire up the creation of a vibrant and sustaining science and technology environment for an ecosystem of large, small, local and foreign enterprises to develop.*[7]

This led to a proposal that Singapore replace its Science Council by a National Science and Technology Board. Moreover, around the same time, a paper submitted to the Ministry of Finance proposing the establishment of institutes of advanced engineering identified the goals of these institutes as:

- *To undertake R&D and develop Centres of Excellence in selected areas of advanced engineering research relevant to the critical needs of Singapore industry;*
- *To train and develop a pool of industry oriented researchers because the universities do not always train industry ready researchers;*

5 www.moe.gov.sg/media/speeches/2010/10/06/speech-by-mrs-tan-ching-yee-launch-mechanobiology-institute.php
6 www.nature.com/naturejobs/science/articles/10.1038/nj0362
7 www.a-star.edu.sg/Portals/0/aboutastar/2012_Commemorative_Pub_Webv6.pdf page 43

- *To participate in joint research programmes and provide technical assistance and consultancy to help Singapore firms to develop;*
- *To develop effective mechanisms for rapid transfer to industry of research findings and technology generated in the Institutes.*[8]

The second of these goals is particularly informative because it acknowledged that universities play a distinct and different role from the proposed research institutes – and the implication was that the centres were necessary to complement but not replace universities, because both were seen as necessary to national development.

The National Science and Technology Board (NSTB) began operation in January 1991 and fell under the auspices of the Ministry for Trade and Industry.[9] The Board prepared Singapore's first five year National Technology Plan, with a budget of S$2 billion, to set the directions for the development of science and technology in Singapore. This was Singapore's first major investment in research. The plan emphasised the need for research that would contribute to national competitiveness; that Government must work in close collaboration with industry; and that government's research institutes must support and complement industries' efforts in working towards a common end. These themes are apparent in all subsequent plans.

In its first decade NSTB served essentially as a funding agency and provided money to the universities which then hired the researchers for the new research institutes. One reason for this was to provide the researchers with a greater sense of security – should the institutes close, the universities could take on their staff. This arrangement also facilitated collaboration between the institutes and the university. However, as they developed, the research institutes gradually moved from their university origins and grew through their industry relevance and industry links, both of which were the outcome of deliberate and strategic development.

The second National Science and Technology Plan covering 1996-2000 had a budget of S$4 billion and focused on supporting manufacturing and services industries, with a key objective being to encourage corporate research and development centres to locate in Singapore.

In January 2002, NSTB became the Agency for Science, Technology and Research (A*STAR) and was given the primary mission of raising the level of science and technology in Singapore, so as to develop and attract higher value, knowledge-based industries. A*STAR encompassed two research councils. The Science and Engineering Research Council (SERC) became the overarching group for the physical sciences and engineering institutes which would support manufacturing, particularly in the electronics, communications, chemicals and general engineering sectors. The Biomedical Research Council (BMRC) has a focus on developing public sector research and talent development in the biomedical sciences.

A*STAR also took direct responsibility for the research institutes, thereby bringing them all under the umbrella of a single organisation. This had a number of objectives. One was to bring related research institutes together, to facilitate collaboration and to avoid duplication; another was to ensure that Singapore's research agenda was set by a single agency, rather than being the result of a multitude of decisions made by researchers in universities and disparate research institutes. This change in organisation also served to emphasise that the research institutes were there to complement, not duplicate, university research. A*STAR also continued to work with the EDB to attract major private research and development activities to Singapore through its strategy of holistically integrating the nation's research capabilities to serve industry needs.

8 www.a-star.edu.sg/Portals/0/aboutastar/2012_Commemorative_Pub_Webv6.pdf page 44

9 A clear demonstration of the explicitly economic role of the NSTB was that it had and maintained close links with the EDB. For example, in February 2001 Philip Yeo became Executive Chairman of NSTB and Co-Chairman of EDB, swapping positions with NSTB Chairman Teo Ming Kian who then became EDB Chairman and Co-Chairman of NSTB.

The third five year plan's budget included S$4 billion to A*STAR to boost local research and development capabilities, and S$2 billion to EDB to promote private sector research and development in Singapore and ran from 2001 to 2005.

In *Science and Technology 2010*, the fourth of the five year national plans, the government allocated S$13.55 billion to different agencies to promote research and development. Of this, S$5 billion went to the National Research Foundation for longer-term strategic programs; S$7.5 billion to the Ministry of Trade and Industry for economic-oriented research and development and related investment promotion activities; and S$1.05 billion to the Ministry of Education for academic research.[10]

The most recent five year plan invests S$16.1 billion over 2011-2015 (a 20 per cent increase over the amount invested 2006-2010) and has six main thrusts: continued support for basic research; a continued focus on talent attraction and development; more emphasis on competitive funding; the fostering of increased private-public sector collaboration; a stronger focus on economic outcomes; and strengthened support for commercialisation activities.[11]

Singapore's post-secondary education system

The Singapore government has placed a high priority on education and this has had considerable effect, as shown by the figures below for the educational attainment of resident non-students in 2010.

	15-24 years	25-39 years	40-54 years	55 years and over
Diploma and professional qualification (%)	33.9	22.5	12.0	4.8
University (%)	11.8	44.1	19.9	6.1

An increasing proportion of the population is receiving a university or other post-secondary education and in addition Singapore has put considerable effort into recruiting top scientists from overseas by offering them globally competitive salaries and conditions. One measure of this is that the number of researchers per million of population grew by nearly 50 per cent between 2000 and 2007. In 2010 there were 19 566 students enrolled in higher degree courses.

The development of Singapore's education system has been the responsibility of the Ministry of Education, which also provides research funding for the universities and polytechnics.[12] While separate from the innovation policies and programs developed through the five year national science and technology plans, education and the development of the education system has clearly played an essential supporting role. In particular, the education system has produced a workforce that can meet the needs of companies attracted to Singapore as well as the needs of indigenous firms; and it has provided a world class research capability and infrastructure complementing that of the research institutes and business research facilities.

The holistic and integrated approach to economic development policies has led to the assimilation of education policy into the broader economic development policy framework. One consequence of this has been that the need for strong linkages between different sectors has been an important integrating theme. An example of the effective integration between policies is that there are government run programs to attract top talent to Singapore to add to and complement the development of indigenous talent through the country's own education and research systems.

10 app.mti.gov.sg/data/pages/885/doc/S&T%20Plan%202010%20Report%20(Final%20as%20of%2010%20Mar%2006).pdf
11 app.mti.gov.sg/data/pages/885/doc/RIE2015.pdf
12 www.moe.gov.sg/education/post-secondary

Singapore's higher education system is more differentiated and with a greater degree of specialisation between individual institutions than found in Australia. This clearly has implications for the relationships that individual institutions develop with business, given the different outputs and outcomes each of the specialised institutions is striving to achieve.

Universities

In 2010 Singapore's universities had a total enrolment of 74 534 students and 4 220 teachers. The undergraduate courses offered by the universities require three to four years of study and their stated aim is to prepare students "not only for today's world but also for a world where there will be jobs that have yet to be invented and challenges not yet foreseen".

The universities play an important role in performing research and are increasing their research quality and quantity. For the period 2004-2008, the National University of Singapore (NUS) increased its overall number of citations by 14% to 97 560, and Nanyang Technological University (NTU) by 25% to 30 693, when compared with 2003-2007. In 2010 both NTU (8th) and NUS (9th) were amongst the top 10 universities in the world in engineering citations.[13] The universities are able to bid for research funding from the Ministry of Education's Academic Research Fund, from A*STAR and from the National Research Foundation.

The universities are responsible for the training of researchers and this training recognises the needs of business. For example, the Economic Development Board runs an Industrial Postgraduate Program which supports the training of Masters and PhD students who are working on industry projects and co-supervised by companies and universities; and ten per cent of the Ministry of Education's Research Scholarship funding supports industry-relevant research training. The universities also nurture research and development collaborations with the private sector, often through large multiparty research consortia including research institutes and both multinational enterprises and local SMEs, but sometimes through bilateral arrangements.

As can be seen from the listing below, there is significant diversity among the universities, reflecting the courses they offer, the way in which they provide them and whether they are public or private. Some are highly specialised, focused on providing a general business education or skills that meet demand in a limited number of industrial sectors. Others are more comprehensive in their operations. The publicly funded autonomous universities in particular aim at an education that goes beyond the present day needs of business to create graduates having knowledge and skills beyond those that business currently needs. There is also differentiation in the market that they serve, for example with the private SIM University specifically catering for part time learning and for students who are already working in business. Of particular note is the strong emphasis on business education and the development of management skills, especially among the private universities.

Autonomous Universities

The autonomous universities receive substantial government funding but have the independence to "chart their own destiny, differentiate themselves and pursue new heights of excellence in education, research and service".

The National University of Singapore (NUS)[14], established in August 1980 from the merger of two other institutions, provides a wide range of degree courses and strives to provide a balanced, high quality education that nurtures the spirit of inquiry and initiative. It has 14 faculties and schools of which offer nine courses leading to first and higher degrees, two offer first degrees only and three

13 www.moe.gov.sg/media/speeches/2010/10/06/speech-by-mrs-tan-ching-yee-launch-mechanobiology-institute.php

14 www.nus.edu.sg

offer higher degrees only. NUS hosts three of Singapore's five Research Centres of Excellence (and hosts another one jointly with the Nanyang Technological University); and has around 25 specialist research institutes to promote research and advanced training. The university runs a number of joint degree programs with overseas institutions (Duke-NUS, MIT-NUS, Georgia Tech-NUS, Imperial College-NUS, Karolinska Institute-NUS). The university has established NUS Enterprise, the CEO of which reports directly to the university President, works closely with the Deputy President (Research and Technology) and oversees all the entrepreneurial and commercial activities of the university.

The Nanyang Technological University (NTU)[15], inaugurated in 1991 but building on the former Nanyang Technological Institute, is a research-intensive university with strengths in science and engineering. It provides a broad-based education, internship opportunities and undergraduate research projects. The Lee Kong Chian School of Medicine (a collaboration between NTU and Imperial College London) will admit its first batch of undergraduates in 2013. The Nanyang Technological University, ranked 16th in the *Times Higher Education 100 Under 50* list of the world's best 100 universities under the age of 50 years. The university has four colleges with 12 schools which offer undergraduate and a range of graduate programs.

The Singapore Management University (SMU)[16] offers a broad-based business curriculum modelled after that of the Wharton School of the University of Pennsylvania and offers bachelors, masters and PhD programs. The university emphasises multi-disciplinary, industry relevant research and has established research centres and institutes in partnership with the business community.

The Singapore University of Technology and Design (SUTD)[17], established in collaboration with the Massachusetts Institute of Technology and Zhejiang University and incorporated in July 2009, focuses on technology-intensive design education in engineering and architecture. It has a strong focus on innovation and entrepreneurship and aims to be a top tier research intensive university producing technically grounded leaders and innovators.

Publicly-Funded Institutions

The Singapore Institute of Technology (SIT)[18], established in September 2009, provides an industry-focused university education for polytechnic graduates, in partnership with the five polytechnics and overseas institutions such as the Technical University of Munich, University of Manchester and Digipen Institute of Technology. It covers disciplines such as engineering and applied sciences, health sciences, and interactive digital media. The Institute also offers part time degree courses to cater to working professionals.

Private Universities – Comprehensive

SIM University (UniSIM)[19] provides university education to working professionals and adult learners by adopting a flexible learning approach to enable its learners to balance their career, family and studies. The Ministry of Education provides fees subsidies for UniSIM's part-time undergraduate degree programs.

Private Universities / Institutions – Specialised

The University of Chicago Booth School of Business Asia Campus[20] delivers an Executive MBA program to provide senior managers and executives with the most up-to-date management education.

15 www.ntu.edu.sg/Pages/default.aspx
16 www.smu.edu.sg
17 www.sutd.edu.sg
18 www.singaporetech.edu.sg
19 www.unisim.edu.sg/Pages/UNISIM.aspx
20 www.chicagobooth.edu/visit/singapore

DigiPen Institute of Technology Singapore[21] is the first international branch campus of DigiPen Institute of Technology in Redmond, Washington. It offers degrees in Real-Time Interactive Simulation, Production Animation and Game Design to prepare students to enter the digital interactive industries in Singapore and abroad.

EDHEC Risk Institute-Asia[22] serves as a platform for generating and disseminating academic insight into investment issues of global importance and of particular relevance to investors and institutions in Asia. Drawing upon its research expertise and senior faculty, it offers the whole range of its executive seminars and degree courses in Singapore, including a PhD in Finance (residential and executive tracks) and an Executive MSc in Risk and Investment Management.

ESSEC Business School[23] is a major player in international management education. And its Singapore campus offers executive programs, part of the MBA in conjunction with the Paris campus, and two Advanced Master's degrees in International Business and in Finance.

German Institute of Science and Technology-TUM Asia[24] is a subsidiary of Technische Universität München (TUM), one of Germany's first three "elite universities". TUM Asia offers joint postgraduate degree programs with NUS and NTU, and a Master of Science in Transport and Logistics.

The INSEAD-Wharton Alliance[25] combines INSEAD's resources with those of Wharton's to deliver business education and research.

S P Jain Center of Management[26] is the international initiative of S P Jain Institute of Management & Research, Mumbai and offers an Executive MBA program and a Global MBA program conducted jointly from the campuses in Dubai and Singapore.

Tisch School of the Arts Asia[27] delivers a Master of Fine Arts degree in one of three areas: Animation and Digital Arts, Dramatic Writing and Film Production – the same degrees offered by Tisch School of the Arts in New York City.

The University of Nevada, Las Vegas (UNLV) Singapore[28], established in 2006 currently represents the William F. Harrah College of Hotel Administration, and offers a fully accredited Bachelor of Science degree in Hotel Administration and tourism and casino gaming executive education.

Polytechnics

The five polytechnics provide three year diploma courses and in 2010 were catering to 83 542 students. Each polytechnic specialises in specific fields. Compared to the academic and longer term vision of the universities, polytechnics aim to train middle-level professionals to support the technological and economic development of Singapore. Taking in students with a wide range of abilities, aptitudes and interests, the polytechnics seek to train students with relevant and specific skills for the workplace. Polytechnic graduates are practice-oriented and knowledgeable middle-level professionals, much sought after by industry. The polytechnics also provide continuing education and post-employment professional development programs and services. Polytechnic education has a strong emphasis on practice-based learning. Work attachments with industry partners are part of the curriculum and can vary from 6–8 weeks to 6 months for different courses.

21 singapore.digipen.edu

22 www.edhec-risk.com/Aleducation/PhD_Finance

23 www.essec.edu/discover-essec/essec-asia-pacific.html

24 tum-asia.edu.sg

25 mba.insead.edu/campuses/asia_campus.cfm

26 www.spjain.org

27 www.tischasia.nyu.edu.sg/page/home.html

28 www.unlv.edu.sg

Like universities, polytechnics also conduct research but in doing this they play a different role from universities. In particular, they play an important role in technology transfer, recognising that the capabilities necessary to achieve a major intellectual breakthrough resulting in a new invention can be very different from those needed to convert the invention to a practical proposition for industry. For example, the National Research Foundation administers a Translational Research and Development Grant Scheme which supports polytechnics so that they can carry out translational research on the output from Singapore's universities (and research institutes). The aim of the program is to encourage universities to work with polytechnics and to draw upon their complementary skills and networks to take research breakthroughs to the market. The most recent five year plan notes:

> While the current system adequately supports the creation of new IP, more resources are needed to bridge the gap to market ... Polytechnics will participate more actively in translation of IP. They will partner with both public and private sector to work on translational R&D projects. SMEs can work with the Centres of Innovation (COI) at the polytechnics to prototype, test-bed and productise their ideas.[29]

There are currently five polytechnics in Singapore: Nanyang Polytechnic; Ngee Ann Polytechnic; Republic Polytechnic; Singapore Polytechnic; and Temasek Polytechnic.

Vocational education

The Institute of Technical Education (ITE)[30] offers two year courses and had an enrolment in 2010 of 24 789 students. Its primary role is to ensure that its graduates have technical knowledge and skills that are relevant to industry. ITE is the national authority for the setting of skills standards and the certification of skills. ITE has numerous partnerships with key industry players.

LASALLE College of the Arts and the Nanyang Academy of Fine Arts (NAFA) are private institutions providing post-secondary education in the arts. Both LASALLE and NAFA offer publicly-funded diploma programs. The institutions also offer offshore or externally accredited degree programs which are not funded by the government.

Singapore's research funding

The *UNESCO Science Report 2010* noted that Singapore stands out as the South East Asia and Oceania region's most rapidly growing investor in science.[31] Singapore's Gross Expenditure on Research and Development (GERD) doubled between 2000 and 2007, in the process climbing from 1.9 per cent to 2.5 per cent of GDP. Also between 2000 and 2007, the number of FTE researchers rose by 50% to 6 088 per million population, in part because Singapore scientists working overseas returned.

In 2010, when the government announced that it would allocate S$16.1 billion to support research, innovation and enterprise for the next five years in the new five year plan, it directed 70 per cent of the S$16.1 billion towards economic outcomes.[32] The government also set a target for Singapore achieving a level gross expenditure on research and development of 3.5 per cent of GDP by 2015.

29 app.mti.gov.sg/data/pages/885/doc/RIE2015.pdf

30 www.ite.edu.sg/wps/portal/aboutite

31 The region stretches from Australia and New Zealand to Singapore, Thailand, Indonesia and the 22 Pacific Island countries and territories.

32 app.mti.gov.sg/data/pages/885/doc/RIE2015.pdf

In 2009 the private sector accounted for 61.6 per cent of Singapore's research and development expenditure, compared to the higher education sector's 14.1 per cent. Business expenditure on research and development (BERD) had grown from S$309.5 million in 1990 to S$3 724.5 million in 2009. The table below shows the proportion of the research expenditure going into different areas of research within each sector.[33]

Area of research	Total %	Private sector%	Higher education
Agricultural and food sciences	1.5	2.1	0.3
Engineering and technology	20.6	13.6	26.6
Biomedical and related sciences	61.2	73.5	39.5
Natural sciences (excl. Biological)	10.4	8.4	19.4
Others	6.3	2.4	14.2

Not surprisingly, given their different roles, the research performed by the higher education sector is much more diverse than that performed by the private sector, which devotes almost three quarters of its total effort to the biomedical and related sciences.

Singapore's research funding bodies

Academic Research Council

The Academic Research Council (ARC) recommends direction for academic research policies and strategies in universities.

The government established the Academic Research Fund (AcRF) in 1994 to support academic research in the Singapore universities. The research supported by the AcRF has to fulfil the following four objectives:

- Creating new knowledge which will form the foundation for future innovations and discoveries;
- Enhancing the universities' reputations, making them more attractive to researchers, academics and students, and adding to the overall attractiveness of Singapore as a talent hub;
- Improving the overall quality of education for students by encouraging university staff to be engaged in the latest thinking and discoveries in their fields; and
- Providing quality postgraduate manpower training so as to nurture locally-based talent to meet the needs of academia and the economy.[34]

The fund's budget from 1994-1996 was S$96 million. From then until 2005, the fund stabilised at S$110million per year. In August 2005, the government increased the AcRF to S$1.05 billion for the next five years. From this, the Ministry of Education set aside S$250million for the establishment of Research Centres of Excellence (RCEs) at universities. Co-funding for the RCEs came from the National Research Foundation, which provided another S$500million, making a total of S$750 million.[35]

The most recent five year plan continued the government's commitment to invest in sustaining core capabilities and investigator-led research. The plan increased the Ministry of Education's Academic Research Fund (AcRF) by 15 per cent to support postgraduate training and to fund

33 Data calculated from Yearbook of Statistics Singapore, 2011.

34 www.moe.gov.sg/media/press/2006/pr20060728.htm

35 www.moe.gov.sg/media/parliamentary-replies/2008/09/research-in-universities.php

investigator-led grants. In addition, a new component in the AcRF provides funding for 'worthy interdisciplinary and collaborative' research programs in the universities.[36] This will fund program level research ranging in scale from S$5 million to S$25 million over five years.

The five year plan also introduced a new type of funding for which the universities can put in competitive bids. This is the Industry Alignment Fund which seeks to 'synergise the efforts of researchers in the public and private sectors and encourage knowledge creation that translates to economic outcomes'.

National Research Foundation[37]

The National Research Foundation (NRF) is a department under the Prime Minister's Office. It provides secretariat support to the Research, Innovation and Enterprise Council (chaired by the Prime Minister) and aims to: coordinate the research of different agencies, develop policies and plans to implement the national research and development agenda and allocate funding to implement national research, innovation and enterprise strategies. The mission of the Research, Innovation and Enterprise Council is:

- To advise the Singapore Cabinet on national research and innovation policies and strategies to drive the transformation of Singapore into a knowledge-based economy, with strong capabilities in research and development (R&D); and
- To lead the national drive to promote research, innovation and enterprise, by encouraging new initiatives in knowledge creation in science and technology, and to catalyse new areas of economic growth.

The NRF runs top down strategic research programs but also bottom up schemes such as a Competitive Research Programme Funding Scheme to support cutting edge, high-impact research; a Research Centres of Excellence scheme for Singapore's universities (which receives joint funding from the Ministry of Education); and the Singapore NRF Fellowships which provide an opportunity for brilliant young researchers from all over the world to carry out independent research in Singapore. NRF Fellows receive a five-year research grant, with free choice of research topic and host organisation. Fellows are appointed to tenure-track faculty positions in the Singapore host institutions.[38]

Of particular interest in the context of university-business interactions is NRF's National Framework for Innovation and Enterprise (NFIE). This aims to encourage universities and polytechnics to pursue academic entrepreneurship and turn their research results into commercial products. It also helps entrepreneurs start up technology-based companies.[39] Component programs range from an early stage venture fund and proof of concept grants, to an innovation vouchers scheme to encourage small firms to interact with universities, a university innovation fund, technology incubation schemes, and translational research and development grants for polytechnics. The program also supports an Innovation and Enterprise Institute which proposes policies and programs to encourage innovation.

36 www.moe.gov.sg/media/speeches/2010/10/06/speech-by-mrs-tan-ching-yee-launch-mechanobiology-institute.php

37 www.nrf.gov.sg/nrf/default.aspx

38 www.nrf.gov.sg/nrf/uploadedFiles/2pp%20factsheet%20NRF%203May2012.pdf

39 www.nrf.gov.sg/nrf/uploadedFiles/2pp%20factsheet%20NFRIE%203May2012_v2.pdf

Agency for Science, Technology and Research[40]

A*STAR grants research funding to support extramural research in the universities, hospitals, research centres, and with other local and international partners. This is in addition to the research it conducts through its own 14 biomedical sciences and physical sciences and engineering research institutes, and six consortia and centres, located in Biopolis and Fusionopolis. Based on Nature Asia-Pacific Publishing Rankings 2009, A*STAR was the 7th most prolific agency in the Asia-Pacific region in terms of papers published in Nature branded journals, ranking ahead of the Australian National University .

The A*STAR Graduate Academy provides a variety of awards that among other things enable Singaporeans to pursue undergraduate and PhD science studies at the top universities anywhere in the world, fund young PhD graduates to gain postdoctoral experience at the best laboratories (including corporate laboratories) anywhere in the world and which enable overseas students to work in Singapore.

A*STAR actively promotes interactions between research and industry to accelerate the translation of research findings into tangible benefits for the economy. From offering technical advice and funding for its scientists to protect and commercialise their intellectual property, to the seconding of research scientists to companies and the sharing of the many facilities available at Biopolis and Fusionopolis, A*STAR has a clear focus on building up industrial capital for Singapore.[41] A*STAR has played a particularly prominent role in developing partnerships and links between basic and applied research and across public sector agencies, research institutes, universities, the clinical community and industry.

National Medical Research Council[42]

The National Medical Research Council oversees the development and advancement of medical research in Singapore. It provides research funds to healthcare institutions, awards competitive research funds for individual projects and is responsible for the development of clinician-scientists through awards and fellowships.

Economic Development Board[43]

The Board runs a number of incentive schemes for companies, including schemes that encourage investment in research and development by providing co-funding to support the set-up of research and development centres, and/or the development of in-house research capabilities in strategic areas of technology; and co-funding to support the manpower development in the application of new technologies, industrial research and professional know-how.

Innovation support through the tax system

In addition to the direct funding of research and innovation activities, the government supports these activities through its tax system – and again, the range of tax deductions illustrates the broad view that the government takes of innovation. The government introduced its Productivity and Innovation Credit (PIC) in its 2010 budget and enhanced the credit in its 2011 and 2012

40 www.a-star.edu.sg

41 www.a-star.edu.sg/Industry/Overview/tabid/171/Default.aspx

42 www.nmrc.gov.sg/content/nmrc_internet/home.html

43 www.edb.gov.sg/edb/sg/en_uk/index.html?cmpid=edb_en38

budgets so that it now provides tax benefits for investments by businesses in a broad range of activities along the innovation value chain.[44] The six activities that qualify for PIC benefits are the:

- acquisition or leasing of specific automation equipment;
- training of employees;
- acquisition of Intellectual Property Rights;
- registration of patents, trademarks, designs and plant varieties;
- research and development activities; and
- investment in approved design projects.

For 2011 to 2015, all businesses can enjoy deduction/allowances at 400 per cent on up to S$400 000 of their expenditure per year on each of the six qualifying activities. For research and development the eligible expenditure includes costs incurred on staff and consumables for qualifying activities carried out in Singapore (or overseas if the research and development done overseas is related to the taxpayer's Singapore trade or business). This includes expenditure on research contracted to universities and for research performed in Singapore the balance of qualifying expenditure exceeding the cap receives a deduction of 150 per cent.

University-business linkages

As in other countries, Singapore's universities have developed a wide range of linkages with business using a variety of mechanisms. While it is not easy to quantify, the policy environment within which they have developed, and the specialised nature of many of the universities, may mean that at least some universities have closer and perhaps more responsive business links than universities in some other countries.[45] Certainly, the need to support economic development and the importance of universities, university educated people and research in supporting this development and in attracting business to the island seem embedded in the national culture and to find a high degree of acceptance.

Of particular importance may be that the State takes an active and high profile role in marketing to business (including overseas business) the country's educational and research capabilities – and in doing so provides information on the other advantages that Singapore can offer business including details of its broader business support programs. This goes beyond what individual universities are able to do; and the low sovereign risk associated with doing business in Singapore is likely to add to the effectiveness of the government campaigns. An important factor in the development of university business linkages is that all parties see the benefit and the mutual advantage that strong linkages can provide.

As an example of the nature of the linkages that exist, the following paragraphs examine how the National University of Singapore (NUS) describes how it works with business.[46]

As in other countries, the major contribution of the universities arises from the education of students who then move to positions in other sectors, taking with them the knowledge, skills and capabilities that their education has developed. However, the NUS emphasises in addition

44 www.iras.gov.sg/irashome/PIcredit.aspx

45 According to one source, partnerships between industry and research performers have increased with the number of industry collaborations initiated between 2006 and 2008 almost doubling the combined totals of the period 2000 – 2005. See: www.nature.com/naturejobs/science/articles/10.1038/nj0362

46 Information based on Professor Barry Halliwell, Tan Chin Tuan Centennial Professor, Deputy President (Research & Technology) National University of Singapore: PICKING RESEARCH PRIORITIES AND CHOOSING COLLABORATIONS IN A CONSTRAINED ENVIRONMENT Elsevier Research Executive Forum Seoul, 08 Jun 2011

the education of its graduates as entrepreneurial leaders. It does this by offering experiential education programs in entrepreneurship in Singapore and globally, and also by supporting NUS student and alumni initiatives and networks related to learning entrepreneurship. As with other universities, the NUS works to facilitate the commercialisation of its research, where this is appropriate, through a professionally-run industry liaison office service; and works to nurture the creation of successful NUS spin-offs through a professionally-run incubator, seed-funding and mentoring system as well as through leveraging the NUS alumni network in business and enterprise. As well as recognising that university research helps create new intellectual property which can help support and grow industry, the university also offers consultancy services which enable business to tap into university expertise and into the knowledge held within the university. The university also cooperates with business in graduate education.

One of the noteworthy features running through these activities is the effective use of alumni. This active engagement with alumni may well have other benefits – for example in relation to philanthropic donations. The NUS is also explicit about the intangible benefits it provides to Singapore's innovation system. For example, the university promotes the fact that its capabilities and reputation help attract to Singapore high-level overseas industry. Moreover the university acknowledges that the benefits of different forms of business linkages do not flow in a single direction. Having industrial laboratories and other facilities located on the university campus can provide academics easy access to leading edge research as well as access to facilities that might not otherwise be available; and the opportunity to engage business researchers in both undergraduate and graduate education provides another significant benefit.

Singapore's small size helps facilitate collaboration between different sectors of the innovation system because complementary facilities are almost inevitably close to each other. But this is again an advantage the government recognises and promotes and on which it quite explicitly builds. For example, the National Research Foundation is currently developing the Campus for Research Excellence and Technological Enterprise (CREATE) at a site co-located with the National University of Singapore's University town. The purpose of CREATE is to attract research centres from major universities and corporations worldwide; and the design and architecture of CREATE have the aim of promoting and inspiring interaction beyond its laboratories. Similarly, the construction close to each other of the two major research complexes of Biopolis and Fusionopolis (which house corporate laboratories as well as public research institutes) at sites close to universities and hospitals had the deliberate aim of encouraging collaboration across sectors and disciplines.

Singapore's approach has been to encourage and promote the development of close linkages between public sector research and business using policies, programs and the building of facilities in close proximity to each other. At the same time, this has taken place within a framework that has recognised and maintains the different roles and responsibilities of the different sectors and of the institutions within each sector. For this reason it is not possible to examine the role of universities in isolation as the 'whole of Singapore' approach emphasises the complementarities that exist between different parts of the national innovation system. This goes beyond the promotion of public private partnerships to the development of meaningful collaborations between different disciplines.

Conclusion

Singapore provides an example of a country responding in a coherent and strategic way to its natural advantages and its lack of natural resources. An important part of this response has been to develop whole of government approaches to national development that focus on the need to build competitive advantage through innovation. Government process and policies recognise the need to take a long term, whole of system view and build up the capabilities of its population while creating the opportunities that a well educated population can exploit.

Investment in education has responded to the needs of national development. The outcome has been a high quality but diverse system with specialised institutions using the best pedagogical approaches from around the world, each working to achieve its own clearly defined educational objectives. Excellence in vocational education is seen as important as excellence in university education because both are necessary; and the institutions responsible for each complement each other and collaborate in many ways.

The clearly defined and differentiated missions of the various teaching and education institutions explicitly meet different needs within the broader innovation system; while the diversity of roles, responsibilities and approaches facilitates specialisation and differentiation through innovation.

A major focus of public investment in research has been economic development (and this is the objective of 70 per cent of public research funding).[47] However, programs to attract business and business research activity supplement the direct investment in public research and provide a strong base from which to foster collaboration. Along with broader business support programs, these help in creating (or importing) the capabilities needed to make effective use of public sector research outputs.

A strong university and university research system has played an important role in attracting business but also in attracting talented people from around the world. A well differentiated university system has provided the educated population having the breadth of diverse skills necessary to run a competitive business and exploit the opportunities that research can create.

Clearly, the policies and programs used in Singapore build on the particular characteristics of that country, not least its culture and the strong, long standing, entrepreneurial spirit of its population. Nevertheless, it appears that a strong, national, enduring vision and an acceptance of the need to build on human capital rather than natural resources for national economic and social development have been important factors in promoting and facilitating flows of information, people technology and funding between the education sector and business.

47 By way of contrast, in 2008-09 only 23.8 per cent of higher education research and 33.9 per cent of government research in Australia aimed at economic development (www.abs.gov.au/AUSSTATS/abs@.nsf/Latestproducts/8112.0Main%20Features32008-09?opendocument&tabname=Summary&prodno=8112.0&issue=2008-09&num=&view=)

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