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An Analytical Framework for Science Parks and Technology Districts with an Application to Singapore*

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Abstract

This paper analyzes the question: what does it take for science parks and technology districts to evolve and grow? We propose an analytical framework to examine the gestation, evolution and sustainability of science parks and regional phenomena at a broader scale such as technology districts. The framework comprises three aspects of a science park's development: growth mechanisms, level of technological capabilities, and integration with national or global markets. The main growth mechanisms we identify are government-led infrastructure provision, agglomeration effects and continual self-renewal through the creation of new businesses. We apply this framework to analyze Singapore's science park strategy and the recent One-North initiative.

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1. Introduction

Since the 1970s, many countries have established science parks and technology districts as part of a strategy to develop new engines of growth. According to Felsenstein (1994), science parks were generally established with two primary objectives in mind. The first objective of a science park is to be a seedbed and an enclave for technology, and "to play an incubator role, nurturing the development and growth of new, small, high-tech firms, facilitating the transfer of university know-how to tenant companies, encouraging the development of faculty-based spin-offs and stimulating the development of innovative products and processes." The second objective is to act as a catalyst for regional economic development or revitalization, and to promote economic growth.

Many Asian countries, including Singapore and Malaysia, have invested in and developed science parks with these objectives in mind. Some governments had also hoped that they will also help to: (a) raise the level of technological sophistication of local industries, through the promotion of industrial R&D; (b) promote foreign investments, especially in higher value-added activities; and (c) accelerate the transition from a labor-intensive to a knowledge-intensive economy. In the late 1990s, many Asian governments were particularly keen to invest in new science parks in an attempt to enhance economic competitiveness and to replicate the success of Silicon Valley.

These developments lead to a number of research issues, which provide the motivation for this paper. Specifically, we seek to develop a framework that provides a theoretical basis for tracing the development of science parks, and to situate the different types of science parks in terms of their gestation and subsequent evolution[1]. We address the following questions in this paper:

(a) Are there common lessons to be learnt from the development of different science parks around the world?

[1] According to Porter (1991), a "framework … encompasses many variables and seeks to capture much of the complexity of actual situations. Frameworks identify the relevant variables and the questions which the user must answer in order to develop conclusions tailored to a particular industry and company".

(b) What does it take for a science park to evolve, grow and renew itself?

(c) Is there a framework that traces the evolutionary path of science parks?

Our objective is to develop a framework that will help situate evolving science parks and to understand the future development of these entities.

While there are different models of science parks, a science park generally encompasses business support and technology transfer mechanisms that encourage and support the start up, incubation and development of innovation-led, high growth, knowledge-based businesses. Most science parks also have formal and operational links with institutions such as universities and other research organizations. Although science parks are supposed to provide focal points for R&D and innovation, the types of R&D conducted and the sectors they focus on will vary. Some science parks and technology districts are focused on basic research (e.g. the Cambridge Science Park), while others are focused on applied research (e.g. the Singapore Science Park). There are also science parks and technology districts that possess strong manufacturing capabilities, either within the park itself or in its vicinity (e.g. the Hsinchu Technology District in Taiwan). By attracting new firms to locate within or in its vicinity, science parks can create substantial agglomerative effects.

The plan for the rest of the paper is as follows. We briefly review recent studies on the development and operation of science parks in Section 2. This review serves as the backdrop for us to introduce, in Section 3, an analytical framework that identifies the key factors influencing a science park's development and its growth. The elements of the analytical framework are illustrated with the aid of three well-known exemplars – namely, Silicon Valley, Cambridge Science Park, and Hsinchu Science Park. In Section 4, we apply the analytical framework to an analysis of the Singapore Science Park[2], which is an example of an infrastructure-led model commonly seen in Asia. Section 5 concludes the paper.

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[2] Although we speak of the Singapore Science Park, there are three separate, adjoining parks, separately managed for administrative purposes, but under a common parent company, Ascendas Pte Ltd, which is a government-related company.

2. A Survey of Recent Literature

The literature on science parks sits within two broad areas of study, which we refer to as (a) the "institutional perspective", and (b) the "technology district", originating from the economic geography or regional science field. The "institutional" perspective views a science park as an institution providing assistance to its tenants in specific policy-based or mechanism-based ways. This view emphasizes issues such as the functioning of incubators and degree of spinoffs, and focuses on whether science parks confer competitive advantages to the tenant firms, as well as positive spillover effects to firms located in its vicinity and the regional economy. By contrast, the economic geography perspective views the science park and its surrounding region as an entity consisting of specialized firms with an evolving structure of inter-firm linkages and agglomerative effects. This perspective examines the role and contribution of science parks in the context of regional development (see Storper and Harrison (1991) and Markusen (1995) for examples of this perspective).

The recent literature covers both the institutional and the geographical perspectives. The studies cover a range of geographic localities, such as Storey and Tether (1998), who provided an overview of science parks in Europe; Lofsten and Lindelof (2002 , 2003) on science parks in Sweden; Athreye (2001) on the agglomeration and growth of the Cambridge science district; Saxenian (2001a, 2001b) on the Hsinchu technology district in Taiwan; Bakouros, Mardas and Varsakelis (2002) on science parks in Greece; Conceicao, Heitor, Piperno and Rubini (2001) on Italian technology parks; Kihlgren (2001) on the St. Petersburg Technology Park in Russia; Palmai (2003,) on an innovation park in Hungary; Phillimore (1999) on the Western Australian Technology Park. A summary of the findings of several representative studies is provided in Table A in the Appendix.

In the institutional perspective, the tendency to view and promote science parks as specialized physical infrastructure to house technology companies has led to a particular focus on the direct and tangible contribution of science parks and the institutions and mechanisms within – e.g. job creation and quality of employment, contribution to R&D investment and output, venture capital raised, as well as the roles of universities with the science parks. Another focus is on the challenges of enterprise formation (see, for instance, Lofsten and Lindelof (2003), Bakouros, Mardas and Varsakelis (2002)). The incubation aspect has been broadly addressed in the studies of science parks in the United Kingdom, by Westhead and Storey (1995) and Westhead and Batstone (1998). The issues of financing and the role of universities were examined by Vedovello (1997)) and Lofsten and Lindelof (2002).

3. An Analytical Framework for Science Parks

While both the institutional and geographical perspectives have highlighted the key challenges facing enterprise formation within science parks, our aim in this paper is to understand the broader forces that influence the growth paths of science parks. The central question we ask is: what does it take for a science park, as a system, to evolve and grow? To this end, we identify three primary aspects that are critical to an understanding of how a science park operates and grows over time. These are:

(a) *Growth mechanisms*: These are the factors and capabilities that sustain a science park and enable it to grow over time.

(b) *Technological capabilities*: The aspect is concerned with the development and strengthening of capabilities in R&D and the creation of competitive advantages in specific technology sectors. While a region's technological capabilities are often indirectly addressed in discussions of a region's industrial sectors of competence, we further develop how different regions specialize in the chain of technology production.

(c) *Global role and market integration*: This aspect addresses the linkages between the region and the global or national economies, the degree of integration with regional or global markets, and the creation of the region's niche in the global system.

The factors comprising our analytical framework are concurrently developed from and used to situate the experience of our three exemplars of Silicon Valley, Cambridge Science Park, and Hsinchu Science Park. These were all chosen based on their well-known global success, against which many science parks (including Singapore's Science Park) were modeled after or benchmarked against. They also demonstrate diversity in the way they developed. More importantly, they all demonstrate important attributes necessary for long-term sustainability and growth.

In Table 1, we provide a comparison of the growth factors of the three exemplars. The growth factors are broadly classified into sub-groups: (a) *gestation and takeoff factors*, which provided the initial impetus for the exemplar's establishment and development; (b) *growth-sustaining factors*, which are the capabilities that enable the science park to renew and sustain itself.

INSERT TABLE 1 HERE

According to Florida and Kenney (1990), "(f)or many, if not for most, Americans, Silicon Valley and Route 128 stand out as symbols of economic and technological success". Silicon Valley has become the universal "role model" for science parks and technology districts around the world. Dating back to World War II with the emergence of an electronics cluster in the region, and supported by contributions from early semiconductor pioneers and Stanford University, Silicon Valley has established itself as a high-tech R&D and industrial region.

In Europe, the Cambridge Science Park in the United Kingdom was initiated by Trinity College of Cambridge University in 1970[3]. The Cambridge Science Park took a long time to get going. By 1978, two years after its officially opening, it had only 7 tenants and only 20% of the

[3] The University had commissioned in 1969, a report by the Nobel Laureate Professor Sir Neville Mott, on role of the University in the local economy. The report concluded that it would be in the interest of Britain, the city of Cambridge and the University, to encourage the growth of existing and new science-based industry and other applied research organizations in Cambridge.

total area devoted to the science park was developed. This was partly due to the fact that Trinity College was very selective about the tenants that it allowed into the Cambridge Science Park. However, since then, the broader region itself has attained a reputation as a high-tech region (Green, 2002).

Established a decade later than the Cambridge Science Park, the Hsinchu Technology District was initiated by the Taiwanese government in 1980, with the objective of attracting Taiwanese technologists and entrepreneurs located in the Silicon Valley to return to Taiwan. Presently, Hsinchu houses a thriving cluster of firms employing more than 50,000 people. While the firms have started out as small and medium sized, many have become large global multinationals in their own right (Amsden and Chu, 2003). While the Taiwanese government was responsible for its establishment, it has subsequently maintained a hands-off policy, leaving the private sector to drive the development of Hsinchu.

As we noted earlier, the exemplars we have chosen strongly illustrate the importance of each aspect of our framework. We discuss them in turn.

3.1 Growth Mechanisms

The first aspect of our framework is the set of growth mechanisms that drive a science park's development. In the case of Silicon Valley, what distinguishes it from other technology districts is the way it continually renews itself (Seely Brown and Duguid, 2002). Silicon Valley was the epicenter of several waves of technological innovation (semi-conductors, computers, and more recently IT and e-commerce) and is often the region that first emerges with innovative new technological sectors (Kenney, 2000). Agglomeration effects are also considered to be significant in Silicon Valley, as the concentrations of talent and venture capital financing continually pull in other talent and firms, thereby creating a virtuous cycle.

The success of Silicon Valley can be attributed to a number of competitive advantages that support the creation of new firms: (a) a large pool of technical talent, (b) availability of pre-existing infrastructure and large network of suppliers, (c) access to venture capital, (d) access to excellent educational facilities and research institutions, and (e) well-developed information networks (see Amirahmadi and Saff, 1993; Lee, Miller, Hancock and Rowen, 2000).

Whereas many of Silicon Valley's firms have gone on to become global companies, many of the tenants in the Cambridge Science Park have remained relatively small. This partly reflects the orientation of the Cambridge Science Park towards basic scientific research. While Trinity College limited the tenant base to technology-focused companies, many firms that did not locate within the Cambridge Science Park still benefited from "spillover effects" by locating in its vicinity, with the emergence of a support ecosystem of ancillary services (Green, 2002). The Cambridge Science Park and the surrounding region is estimated to account for 60% of all hi-tech establishments and over 70% of all high-tech employment in the Cambridgeshire Country (Athreye, 2001).

Finally, the Hsinchu Science Park has had considerable success in the creation of technology startups (see Hou and Gee (1993) and Saxenian (2001a, 2001b)). Although many of the startups were initially spun off from the government-linked Industrial Technology Research Institute (ITRI), an abundance of venture capital, technical and managerial talent has emerged over the years to support this and later stage entrepreneurial activities within Hsinchu.

We can discern three types of growth mechanisms: (i) government-directed mechanisms, in the form of infrastructure provision with perhaps a signaling motive; (ii) agglomerative effects; (iii) new-firm creation and self-renewal. We consider these growth mechanisms in turn.

3.1.1 *Government-directed mechanisms*

The primary government-directed mechanisms present in many science parks involves the funding of institutions of research, such as Hsinchu's ITRI, Cambridge University, and Silicon Valley's early defense firms. On the other hand, the primary motivation of many Asian governments is the provision of infrastructure. The development of high-quality infrastructure was also part of a concerted strategy to attract multinational corporations (MNCs) to invest and locate manufacturing as well as R&D operations in these economies. This was the case in

Malaysia, Thailand and Singapore, where the development of science parks was an important part of the efforts to attract foreign investment. The presence of a science park – even one with moderate physical infrastructure and tenuous linkages to universities and research institutions– signals a country's commitment to a high-tech economic growth strategy. As foreign investments flow in and more MNCs locate in the science parks (or neighboring districts), the advantages of the science parks are strengthened.

Unlike Asian economies, the *signaling motive* was not as strong a factor in the establishment of European science parks, although those parks do serve to help attract investments to the region by the presence of the existing firms. This is explained further as a process of agglomeration next.

3.1.2 *Agglomerative effects*

The presence of a science park and a cluster of high-growth technology firms can stimulate job creation and regional growth as new firms, talented labor and investments are drawn to the region. In turn, firms can have access to a greater number and variety of suppliers, technical expertise and potential business partners, all located within close proximity. The agglomerative forces also include knowledge *spillovers*, resulting from the informal transfers of knowledge and exchange of ideas.

Silicon Valley exemplifies this process, and provides the benchmark against which other innovative regions are assessed (Kenney, 2000). For European science parks, *agglomerative effects* were important considerations for their establishment and long-term sustainability. In Asia, though, agglomerative effects were not often cited as the primary reasons for the establishment of science parks, as noted in Xue (1995), for example.

3.1.3 *New firm creation and self-renewal*

The single most critical factor for a science park's long-term sustainability is its ability to foster the creation of new firms, in both existing and emerging sectors, in order to continually renew itself. This was the key factor in Silicon Valley's success (Lee, Miller, Hancock and

Rowen, 2000). Many science parks have sought to enhance their capabilities in this process with the establishment of incubators and co-location of venture capital firms to accelerate the entrepreneurial process.

A region's existing capability to generate new research and other knowledge is an important factor in the new-firm creation process. In the case of Cambridge and Silicon Valley, the presence of world class universities and other research institutions helped stimulate the entrepreneurial process, partly as new firms were spun off from the research programs of these institutions, and partly as these institutions served to draw new firms desiring some spillovers from those institutions. Other important factors include the proximity to centers of commerce, the willingness of established businesses to try new technology products (i.e. as early adopters and customers), and a high-quality workforce.

As a whole, these factors will draw in new firms, and ultimately strengthen the agglomerative forces. Clearly, if a science park or technology district is unable to renew itself through new sources of growth, decline will set in. Some researchers have commented that this was perhaps a reason underlying the relative lack of vitality in Boston's Route 128, since the late 1970s, relative to Silicon Valley.[4]

3.2 Technological Capabilities

The second aspect of our analytical framework is the level of research or technology development capabilities within a science park or technology district. This aspect is important for assessing the current status of technological sophistication and the level that is aspired to. The R&D framework presented in Amsden and Tschang (2003) is applied to this purpose. In the simplest possible terms, this typology consists of five categories, as described in Table 2 below. The R&D stages range from pure science and basic research (involving fundamentally similar

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[4] Saxenian's (1994) earlier study contrasted the different "cultures" of Silicon Valley and Route 128, as well as the latter's dependence on government funding. Silicon Valley's ability to find new sources of growth, and renew itself has been extensively studied. A recent study is Bresnahan, Gambardella, Saxenian, Wallsten (2001).

techniques and results, but different motivations) to applied research (involving research oriented to more practical, product-related considerations), to exploratory development, (involving prototyping) and to advanced development (involving manufacturing considerations).

INSERT TABLE 2 HERE

We use this typology to classify the technological capabilities of the three exemplars. Silicon Valley has established itself as a global hub for both basic and applied research (Saxenian, 1994), although a sizable amount of R&D is also conducted in applied research and product development. Its phenomenal growth is oriented around specific technology sectors and concentrations of firms which took ideas out of labs and into the commercial world. While government defense spending in the 1950s catalyzed the development of Silicon Valley, it was the technology companies spun off from both the universities and established companies such as Fairchild Semiconductor that propelled growth in the 1960s. Other successful waves of companies included those in computers, e.g. Silicon Graphics, Apple Computer and Sun Microsystems, and more recently, those oriented around networks and other new computing technologies. These companies played a role in shaping the global production networks that emanate from Silicon Valley (Florida and Kenny, 1988).

In the case of the Cambridge Science Park, the main type of R&D appears to be the pure science research output of Cambridge University and other nationally-funded research institutes in the region. In the 1970s and 1980s, many of the companies that originated from the Cambridge Science Park were led by research scientists who were first-time entrepreneurs. The initial focus was in electronics and software, which broadened to other technology sectors later. Increasingly, major companies with strong science and technology resources have also based research outposts in Cambridge. As a result of all this, in the 1990s, biotechnology, R&D consultancy and software were the key sectors in the Cambridge Science Park.

The specialization of the Hsinchu Science District is primarily in production-oriented technology (Lee and Yang, 2000) – what we term exploratory development and advanced development. Hsinchu's development has benefited from institutions such as the National Chiao Tung University, the National Tsing Hua University and the Industrial Technology Research Institute, as well as the three national laboratories – National Center for High Performance Computing, the Synchronous Radiation Research Center, and the National Space Program Office.

3.3 Global or National Role Definition and Integration of Markets

The third and final aspect of our framework consists of the linkages that a given science park has (particularly with the national and global economies), and as a result, the role or niche it plays. At the national level, this may concern the ability of the economy to commercialize the output of the science park's research, and to offer a viable market for its products. At the global level, this may concern the ability of a region to connect with different regions and the global value chain. Science parks that cannot match the sophistication of the technologically more advanced players must find and develop an alternate role, such as the production of products and services that can serve the local or national economy (Seely Brown and Duguid, 2002).

The three exemplars exhibit different levels of interaction with the national and global economies. Silicon Valley is home to a large number of enterprises that have globalized their operations while retaining their R&D core in the Silicon Valley region (Lee, Miller, Hancock and Rowen, 2000). It is considered a global R&D leader and "the market to be in" for many technology sectors. As a global hub for both emerging technologies and venture capital, it has strong linkages with other technology districts in other countries.

By contrast, Cambridge Science Park has acted mainly as a magnet within the United Kingdom for global and national enterprises to locate in its vicinity (e.g. Microsoft's first non-US laboratories were established in Cambridge, U.K.). With Cambridge University playing a key role in fostering university-industry linkages, the broader Cambridge science district has provided a vibrant environment for science-based industries. Athreye (2001) argues that Cambridge is unique among all other IT clusters that followed in the wake of Silicon Valley's success in that no other European region has shown the same scale of entrepreneurial activity as Cambridge or developed a similar set of institutions without state intervention. However, in marked contrast to Silicon Valley, Cambridge's global impact has been limited. The number of large technology firms in the Cambridge area remains low, and few have made a significant contribution at the national or global level (Athreye, (2001), Green (2002)).

Although it lags behind in the capabilities to develop cutting edge technology, Hsinchu is generally regarded as a key player in the manufacturing of new semi-conductor and other electronic technologies. Firms located in Hsinchu are among the top manufacturers of personal computer-related systems and components. It has developed strong links with Silicon Valley, effectively becoming part of the latter's global network (Saxenian, 2001a). These linkages extend to cross-border investment flows, key manufacturing partnerships between Taiwanese and US firms, and the transfer of entrepreneurial talent and management practices from Silicon Valley into Taiwan. In 1988, 109 of the 272 companies established in the Hsinchu district in 1998 were founded by Taiwanese entrepreneurs who have had managerial, business and entrepreneurial experience in the United States (Lee and Yang, 2000).

3.4 Summary

From the above discussion, we can discern different models of successful science park development. While Silicon Valley became a global hub for R&D with considerable success in creating world-class companies, Hsinchu plugged itself into Silicon Valley's extended global network, and Cambridge has acted as a magnet for technology startups keen to take advantage of the facilities it offers. In each of the models, the most important trait for sustaining growth is that of an ability to attract or create new firms. A common factor that underlies the success of the exemplars is the access to talent. All these factors underline the ability to generate new sources of growth in the form of new technologies and products for global markets.

Hsinchu provides an interesting contrast to Cambridge and Silicon Valley. A primary motivation in its establishment was to provide high-quality infrastructure to support technology startups and help develop national capabilities in high-tech manufacturing. Mechanisms were put in place to facilitate the transfer of know-how from research institutions to the private sector. Agglomerative effects were equally important in the subsequent development of Hsinchu, and although the government provided the initial stimulus, it was the private sector that drove its subsequent development (Saxenian 2001a, 2001b).

By contrast, neither Cambridge nor Silicon Valley was pre-occupied with infrastructural concerns. Instead, the desire to commercialize new technologies and products was the principal motivation in the early development of both Cambridge and Silicon Valley. Their evolutionary paths, however, have been different since. Silicon Valley is a global hub in both R&D innovation and in production. Although Cambridge has a limited role in global production, it is also one of the global clusters of intellectual development and research.

4. An Application of the Analytical Framework to Singapore

We turn our focus next to an analysis of the Singapore Science Park (SSP). The framework we have developed is used to evaluate the SSP, and to examine whether the SSP exhibits hallmark characteristics of a global self-sustaining science park, or whether another fate beckons.

The SSP has been a core component of Singapore's development strategy for the past two decades. As an island economy with little natural resources, an urgent task in the early years of Singapore's independence was to attract MNCs to invest in setting up manufacturing operations in the country. While the strategy had been successful in accelerating economic growth in the 1960s and 1970s, it also led to Singaporean companies playing a largely supporting role to the MNCs. As the cost of doing business escalated and other developing economies offered cheaper locations for manufacturing, this prompted the government to undertake a review of the competitiveness of the Singapore economy. This led to the development of the SSP in 1980.

4.1 The Singapore Science Park Strategy: 1980-2000

The origin and development of the SSP[5] must be viewed against the set of coordinated government policies on science and technology policy (including research and human capital formation), IT infrastructure, and more recently, promotion of entrepreneurship (see Ministry of Trade and Industry, Singapore, 1986, 1991). The SSP has been an integral part of the technology policy that underpins Singapore's economic growth strategy. Like many Asian science parks, one of the initial motivations of the SSP was to provide and upgrade local *infrastructure to* house MNCs as well as new industries which require proximity to the institutions of higher learning. Additionally, the SSP was established to provide a focal point for R&D in Singapore, with an emphasis on industrial R&D. A secondary objective of the SSP was to *signal* Singapore's readiness to develop high tech industries.

The provision of infrastructure went beyond just physical facilities, and included the creation – with government encouragement in the form of tax breaks and other incentives – of a supporting infrastructure for the MNCs. This supporting infrastructure consisted of domestic suppliers, service providers and potential business partners. The multiplier effects of these investments and the development of the supporting infrastructure had significant stimulative effects on the domestic economy.

Singapore's science park strategy has until recently been driven largely by the government. Private sector participation was limited unlike in the case of Silicon Valley or Hsinchu. While there were substantial efforts over the years to define a global role for the SSP, the strategy has only managed to achieve modest levels of success at plugging Singapore into the global network of high technology clusters. There was also little interaction between the actors within the SSP and between them and other regions, although it has improved in recent years.

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[5] Information on the Singapore Science Park can be found at http//:www.sciencepark.com.sg

4.2 The Singapore Science Park Strategy: Into the Future

To extend and complement the SSP, the government is building a new One-North Science Habitat, a 200 hectare development that will integrate the existing science park facilities and other research centers into a mammoth science and technology district.[6] Conceptualized in 2000, the project is estimated to cost S$15 billion, or about US$8.6 billion, over 15 years. It is envisaged to create the ambience of a multifaceted research community, with schools, public transport and other amenities. It will provide a wider focal point for R&D and entrepreneurial activities in the bio-sciences and information technology. In the planning of the project, detailed studies were made on a number of science parks and incubators, including Hsinchu, Cambridge, Silicon Valley, Sophia Antipolis, and the MIT Medialab.

There are a number of areas that distinguishes the One-North master plan from the original SSP. Firstly, it aims to provide infrastructure that offers seamless connectivity, at both the individual and business level. In contrast, the sprawling nature of the existing Science Parks I and II, modeled after the low-density environment in Silicon Valley, does not facilitate close interaction. Secondly, "dynamic planning" will be emphasized in One-North, to encourage the vertical and horizontal integration of tenants and their different uses of the space. The aim is to enable different companies to work closely together and facilitate cross-fertilization of research ideas. Greater private sector participation will be encouraged. For instance, although the bio-medical sciences is a key sector in the first phase of One-North's development – as shown by the large investment in the Biopolis - a new bio-medical research facility[7] - the current thinking is to create self-evolving industrial structures that will allow One-North to catch the next wave of emerging technologies.

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[6] Based on interviews with officials involved in the One-North development project, we understand that the planning and conceptualization of the One-North project took more than a year. Details of the One-North project can be found at http://www.one-north.com.

[7] This facility is being developed a short distance from the SSP and the National University Hospital. The establishment of Biopolis is part of the government's current plan to develop Singapore into a bio-medical hub and to create new engines of growth.

The One-North strategy represents an attempt to address some past deficiencies. While the development of state-of-the-art infrastructure remains a key attraction for overseas companies to locate in One-North, there are also renewed efforts to project Singapore as a regional centre of R&D. The Singapore government is encouraging companies from Australia, New Zealand and elsewhere to locate their R&D activities in Singapore, and position the island become as a gateway the markets in China, India, Southeast Asia and Indo-China.

While the One-North project represents a new approach in Singapore's science park strategy, a key constraint will be the limited pool of technical talent available in Singapore. The Singapore government has recognized this limitation, and has introduced policies aimed at strengthening its technological capabilities and expanding the pool of expertise.[8] For instance, more postgraduate scholarships are being awarded for PhD studies in the sciences and there is a renewed emphasis on basic research (as opposed to the former emphasis on applied research) in the government-funded research institutes and in the local universities. In the short-term, the government is making concerted efforts to attract foreign talent to Singapore to supplement the local talent pool.

4.3 Analyzing Singapore's Science Park Strategy

The evolution of Singapore's science park strategy can be analyzed with our framework. We discuss, in turn, the three aspects of growth mechanisms, technological capabilities and global role definition.

4.3.1 *Growth Mechanisms*

The original SSP was conceived as part of a national policy to promote R&D and to signal the country's readiness to promote high tech industries. As such, the desired *agglomerative* effects were less emphasized in the early stages of its development. Although the MNCs located

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[8] With the benefit of the Hsinchu experience, another objective of the One-North plan is to attract overseas Singaporeans to return home to contribute their talents and entrepreneurial skills, just like in the case of the returnee Taiwanese entrepreneurs from Silicon Valley.

in Science Parks I and II conducted more R&D than Singaporean organizations, the impact on knowledge creation and spillover was limited (Hu and Shin, 2002). Due to Singapore's small size, the agglomerative effects could be as much due to national level advantages than to the SSP. In fact, it can be argued that the whole of Singapore should be considered an "industrial district," since travel time is only two hours from one end of the island to the other, and often less than an hour between key points of business and industry.

As discussed earlier, the ability of a science park to foster the creation of new firms and renew itself is intimately linked to competitive advantages such as the availability of technical talent and R&D capabilities. In Singapore's case, these competitive advantages were relatively weaker than larger, more advanced countries. Although there were attempts in the 1990s to foster entrepreneurial capability by locating the Kent Ridge Digital Laboratory (a large national IT lab) and two venture capital firms in the SSP, this did not translate into successful high-tech spin-offs for the most part.

In many science parks, knowledge spillovers are sometimes more important than physical infrastructure as a source of attraction for potential tenants. Thus, providing better quality infrastructure alone is unlikely to attract firms to new science parks such as One-North at a time when every country in Asia has a surfeit of infrastructure. Already, Malaysia has announced that it will be embarking on a project similar to Biopolis, and is aiming to attract similar companies to those that Singapore's Biopolis is targeting.

Recognizing the challenges ahead and to differentiate itself from other competing new science parks, One-North intends to attract new firms by creating an environment that facilitates spillovers and agglomerative effects through the development of a dense technological metropolis. It intends to create an environment that will allow organizations in different sectors and technological activities to combine their different capabilities into new ones, in the process transforming themselves, as required, to adapt to new situations.

4.3.2 *Technological Capabilities*

One of the biggest difficulties facing Singapore is the expansion and deepening of its technological capabilities. While Singapore's government-funded research institutions and local universities managed to spin off a number of companies in the late 1990s, the combined impact of these efforts within the SSP had been relatively modest. Access to larger markets and the ability to sustain these numbers of entrepreneurs are frequently cited challenges.

Most of these technology spin-offs observed in and around the SSP occurred in 1999 and 2000, just before the burst of the Internet bubble. Many of these startups were launched after reaching the applied research or development stages – that is, after a relatively short 2-3 year period of R&D. Consequently, there was little innovative technology that was embodied in their products or services. Many of these enterprises also had difficulties scaling up their operations to serve a bigger market before other imitators enter and copy their lead. These problems were further compounded by Singapore's small domestic market, which made it necessary for these companies to expand into other Asian markets in order to survive. However, most of these start-up companies lacked the necessary networks and resources to establish a foothold overseas. The outcome is that many of these start-ups declined rapidly and closed down after a couple of years.

Beyond the need to rely on the other parts of the science and technology system, One-North has also expressly addressed the need to increase Singapore's technological capabilities. It plans to attract research-performing firms from overseas (such as firms from Australia and New Zealand) by offering them a superior intellectual property regime, and by providing the best marketing channels to the rest of the Asian region. This presents another challenge, as MNCs already generally preference to locate their overseas R&D operations in markets with an excess of highly skilled labor (e.g. scientists with PhDs) and low costs of operation.

4.3.3 *Global Role Definition and Market Integration*

The success of the Hsinchu Science District has shown that strong linkages to technology centers such as Silicon Valley, via the transnational community of Taiwanese entrepreneurs located in the United States, can have a significant impact on the success of a science park. Like Hsinchu, Singapore sought earlier to create a global role for itself. However, apart from local contract manufacturers which rose to service MNCs located in Singapore, there was no significant transnational community like Hsinchu's to link up startups in Singapore and help them create inroads into the U.S. and European markets.[9]

If One-North's strategy to attract companies to locate their R&D activities in Singapore succeeds, Singapore could then have the basis for defining a role for itself as a regional R&D or R&D commercializing center, either on par with or in connection to new global technological clusters. It remains to be seen how this role evolves: whether Singapore can attract firms and sustain the growth of firms with what is still a foreign investment-led (i.e. infrastructure- and government-policy led) policy, and whether it will then be able to plug itself effectively into a regional production chain, or into the global production chain (as Hsinchu did). Either strategy will not be easy. The former requires developing Singapore as a gateway to other Asian markets, and establishing a regional role for itself in high-tech R&D, perhaps with a constellation of intellectual property protection provider and other resources. On the other hand, a global role requires developing a stellar capability in R&D, so as to serve a more global function as an R&D hub, or to become a manufacturing base, both of which are harder to do when so many countries have increasingly higher skilled but lower wage workers in abundance. The alternative strategy is for One North to develop a role in the national economy, but since Singapore is a city-state, and has a smaller market, this may be a less relevant strategy. Developing a relevant global or regional role effectively sends a strong signal that it is indeed a significant base (for R&D or whatever else) in the region, further helping to consolidate its position.

[9] Singapore's few contract manufacturers are more likely to locate their production and R&D facilities outside of Singapore! Singapore's most globally known product-maker – Creative Technologies – is still limited to niches within the global PC peripherals market.

4.4 The Evolution of Singapore's Science Park Strategy

In our analytical framework, we postulated three aspects in the gestation, evolution and sustainability of science parks; namely, (a) growth mechanisms, (b) level of technological capabilities, and (c) global role definition and integration of markets. The dynamic nature of growth mechanisms and global role definition can be illustrated in Figure 1, which shows the evolution of Silicon Valley, Cambridge and Hsinchu.

All the three exemplars in our study have matured into self-sustaining technology "districts" or regions, in part because of local firms, and have gone beyond their boundaries to develop global linkages and substantial technological capabilities. If Singapore's One-North is successful in developing its growth mechanisms, strengthening its technological capabilities and linking itself to global markets – in short, becoming a self-sustaining hub for research and innovation – Singapore stands a good chance to achieve greater success in defining a global or regional role for itself. In this case, the future growth path for Singapore's science parks could shift course towards the other exemplars, as shown in Figure 1. The task will not be easy, and requires a substantial amount of investment and efforts to develop the supporting institutions in the years ahead.

INSERT FIGURE 1 HERE

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5. Conclusion

Our aim in this paper was to present an analytical framework to study the development of science parks and technology regions, and the factors contributing to their success. The proposed analytical framework focuses on a science park's growth mechanisms, the sophistication of its research capabilities, and the role that it plays in the national and global economy. The framework was built on the experiences of Silicon Valley, Cambridge Science Park and the

Hsinchu Science District. Although the three exemplars differ in their initial growth impetus, they all possess strong self-renewal capabilities in terms of new firm formation, and in cases, growth. Furthermore, these exemplars have continued to sustain the R&D competencies that propelled their initial growth.

Finally, we applied the framework to Singapore's earlier and recent science park strategy to assess its development and to identify the challenges ahead. While the One-North strategy represents a fresh attempt to chart a more aggressive growth path for Singapore's science parks, it is still primarily an instance of the infrastructure-led variety of growth mechanism. Whether the efforts would succeed would depend on how successful One-North can acquire the other requisite growth mechanisms. We believe that greater participation by the private sector, as well as the development of linkages with Silicon Valley and other science parks and technology hubs based on Singapore's own development of strong native capabilities could augur well for the future of Singapore's science parks.

Appendix

Table A: Recent Studies of Science Parks and Technology Districts

Paper	Subject	Key Findings	Remarks
Storey and Tether (1998)	Various science parks in the Europe	1. Science parks in Europe were significantly smaller than those in the U.S.A. 2. Science parks in Europe made modest contributions to employment and technology transfer 3. European science parks also did not seem to spawn rapidly growing science-based enterprises.	1. This was a paper from the "institutional" perspective. 2. The authors compared scale of parks, contributions to economic growth and inability to spawn fast growth science-based enterprise. 3. The authors also argued for more government support to assist technology-based firms to grow.
Lofsten and Lindelof (2003)	Various science parks in Sweden	1. This study compared on-park and off-park firms to analyze the added-value which science parks offer to new technology-based firms (NTBFs). 2. Firms located within science parks had more links with local universities. 3. NTBFs within parks yielded a higher rate of job creation	1. This paper discussed the institutional perspective of science park development focusing on their "added-value". 2. The authors argued for initiatives to promote new technology-based firms within science parks.
Athreye (2001)	Cambridge Hi-Tech Cluster, United Kingdom	1. Cambridge had developed an array of institutions, university-industry links and local technology venture capital that have nurtured entrepreneurship in science-based industries from its humble beginnings. 2. Compared to Silicon Valley, there was an absence of large firms based on product market successes. 3. Growth of employment came mainly from the growth in the number (not the size) of new establishments. 4. Unlike Silicon Valley, Cambridge was not highly specialized in hi-technology production in the U.K. 5. But, there was a significant amount of science-based entrepreneurship and some local network effects among the scientists.	1. This paper projected the "economic-geography" perspective of science park development. 2. It highlighted Cambridge's premier position as a centre for science-based entrepreneurial activity in sectors in Europe.

Paper	Subject	Key Findings	Remarks
Florida and Kenny (1990)	Silicon Valley and Route 128, USA	1. Silicon Valley ("SV") and Route 128 projected the image of freewheeling, high-technology entrepreneurship and quick-shooting venture capital activities. 2. They had created new and highly innovative companies at breakneck speed. They "can catalyze the world's most advanced breakthrough innovations." 3. These centers also generated a high degree of internal competition and a serious problem of industrial fragmentation. 4. The unfortunate reality of SV and Route 128 was one of severe, at times, devastating competition.	1. This study critically appraised the negative "institutional" aspects of success. 2. SV and Route 128 might have stood out as symbols of economic and technological success to the Americans (and the emerging countries of Asia), but they did not "re-invigorate and renew traditional industries". 3. SV's phenomenal growth has bred innovative companies which may not be equipped to follow-on with large-scale product commercialization
Saxenian (2001a)	Hsinchu Science District, Taiwan	1. The Hsinchu region of Taiwan grew from a government effort in 1980 with the development of infrastructure. It started with clusters of small firms. It drew in FDI from the US and Japan, domestic and foreign talents, and Taiwan returnees from SV. It had grown to be a world centre for integrated circuits, computers and peripherals 2. The Hsinchu region, like the SV, was an example of Marshallian external economies, in which the localization of skill, specialized materials and inputs, and technological know how generates cost reductions for individual firms and increasing returns to the region as a whole. It has created an "agglomeration" effect. 3. Inter-firm mobility insured the diffusion of tacit knowledge and facilitates the process of new firm formation. 4. The flows of people, information and know-how linking SV and Hsinchu were so great that the latter is like an extension of SV.	1. This is a paper from both the "institutional" and "economic-geography" perspectives. 2. The author argued that there is an "agglomeration" effect as firms benefited from proximity and inter-firm mobility. 4. The author also observed that the connections between clusters are critical for their success. 5. From our perspective, the domestic alumni network and external connections with Silicon Valley together provided Hsinchu the added advantage for its sustainable growth into the future.

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Table 1: A Comparison of Exemplars of Science Parks and Technology Districts

	Silicon Valley	**Cambridge**	**Hsinchu**
No. of firms (Year)	More than 10000	About 1000 (2002)	272 (2000)
Sectors	R&D, manufacturing (limited)	Scientific R&D	Manufacturing (various)
Gestation factors			
Gestation and early advantage	Initially government led, followed by strong industry and university linkages	University-led effort in its creation, followed by private firms choosing to locate within the park	Government-led effort to build infrastructure and institutions, which provided environment for spin-offs from research institutions
Evolution	Self-directed. Take-off occurred in the 1950s.	Self-directed. Established in 1970.	Government-led with self-direction after spin-offs matured. Established in 1980.
Constraints	Overcrowding has forced some smaller firms to leave. The quality of life has declined somewhat.	Small size of firms. No major industries developed around Cambridge.	Taiwan is still largely a manufacturing base Urgent need to move into innovation.
Growth-sustaining factors			
Tenants	Local firms either spun-off from Stanford University, established firms, or relocating from outside of the region.	Local firms interested to locate near Cambridge Univ., some recent high tech spin-offs (e.g. biotech)	Domestic small and medium enterprises spun-off from government institutes (e.g. ITRI) or founded by returnees from the USA
R&D stages contained within park or region	Mainly known for basic research, but also includes pure science, and applied research	Mainly known for pure science and basic research	Applied research related to design, manufacturing
Additional Enabling factors	A global hub for venture capital financing, technology markets	Strong intellectual capital base attracts continual inflow of entrepreneurial initiatives	Connected to and supported by a global production network (emanating from Silicon Valley)

Source: Silicon Valley: Saxenian (1994), Lee, Miller, Hancock, Rowen (2000).
Cambridge: http://www.cambridgesciencepark.co.uk, Athreye (2001), Green (2002).
Hsinchu: http//www.sipa.gov.tw, Lee and Yang (2000), Saxenian (2001a, 2001b)
Singapore: http//www.sciencepark.com.sg, Amsden and Tschang (2001).

Table 2: A Classification of the Stages of Research and Development

Stage of research	Description of activity and output	Entity performing it and skill requirements
Pure science	Research for the pursuit of knowledge, with outputs usually in scientific journals and possibly patents	Universities (scientific expertise needed)
Basic research	Similar outputs as pure science approach, but conducted with specific long-term corporate objectives (such as future products) in mind	Corporate laboratory (scientific expertise needed)
Applied research	Medium-term research on known technologies; typically involves transforming or localizing existing product knowledge, or re-applying known research results to other areas.	Corporate laboratory (less scientific, more engineering expertise needed)
Exploratory development	Development and prototyping of design and other systems	Corporate product development departments (product development expertise)
Advanced development	Addressing of manufacturing considerations for products	Manufacturers (manufacturing and product development expertise)

Source: Adapted from Amsden and Tschang (2001)

Figure 1: The Growth Path of Singapore's Science Park Strategy