Singapore's Role as ICT Hub in ASEAN:

A View from the New Economic Geography

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Abstract: This paper examines the aspirations of Singapore to be an ICT hub in ASEAN using the concepts developed in the field of the New Economic Geography. It sets out three models for this study that examines the impact of increased economic integration on the changing role of Singapore as a hub; it then applies these models to the study of the ICT goods industry, ICT services industry and ICT infrastructure. Included is a discussion of recent ICT policy in Singapore, and implications of the theory on future policy options for countries in the region. The conclusion is that, when the constant evolution of the economic landscape is seen in the light of necessary private agent choices, a hub role is both sustainable and beneficial to the continued growth and development of the region.

Keywords: ICT Policy in Singapore, New Economic Geography, ASEAN Economic Integration

I. Introduction

Singapore, a small island of 4 million people, aspires to be an ICT hub for the ASEAN region. Beyond wishful thinking, does economic theory provide a possible justification for this desire? To address the question in a slightly different perspective, what does increased integration in the region imply for the location of industry, in particular the ICT industry? The latest research on the New Economic Geography just might provide an answer to this question. This paper will aim to place in context the feasibility of Singapore's recent ICT21 Masterplan with respect to its spatial implications, and at the same time draw some tentative predictions for the emerging ICT industrial distribution for the rest of the region.

The motivation for this is clear: if New Economic Geography theories are able to provide rationalisations for the location of economic activity in the past, then it can possibly well explain what the future economic scene might entail. This is not merely for academic interest, however; such a study would inform government policymakers on the possible approaches to adopt which would facilitate the transition that would spontaneously arise due to the individual decisions of economic actors.

The paper is structured as follows. After this introduction, the next section will provide the background theory by discussing several models of the new economic geography that are relevant to the current discussion. Section III will then review the ICT industry development process in Singapore – specifically, it will discuss the historical evolution of ICT policy in the island-state and its consequent influences on the economic landscape. This is followed by section IV, which provides an analysis of the previous section in light of theory, before the final section concludes.

II. Background theory

This section will confine itself to a non-technical review[1] of three models of the new economic geography. Two are quantitative models centred on increasing returns from positive externalities due to agglomeration; the final is a more qualitative model that introduces important variables such as knowledge spillovers and institutional benefits that are not easily captured quantitatively. The first quantitative model introduces a world with trade costs[2] but

[1] A more detailed exposition of the mathematical models is included in the appendix.

[2] Trade costs here are not necessarily confined to transport costs, but all the various costs involved with engaging in business at a distance, including direct contact, more complex and expensive communications and information

no defined national boundaries (Fujita, Krugman & Venables 1999); the second, one with zero transport costs and (again) homogenous geography, but incorporating the novel concept of time-zones (Quah 2000). The final model introduces concepts of cluster analysis and builds a conceptual model that focuses on competitive advantages in cluster location (Porter 1998).

A seamless world with trade costs

The Fujita, Krugman & Venables (1999) model is based on a Dixit-Stiglitz world where manufacturing is a single, monopolistically competitive sector of many goods. There are two industries in the basic model (which can, without loss of generality, be extended to *n* industries by utilising numerical methods). Forward and backward linkages among firms create forces that support agglomeration, and these are known as centripetal forces. However, there are conflicting centrifugal forces that work against agglomeration due to the trade costs that arise between regions.

In order to address the seemingly intractable problem of determining industrial cluster emergence, a specialised analytical model is employed. This approach, first introduced by Turing (1952) in the field of theoretical biology, involves a selective restriction of focus to the beginning stages of the process of differentiation into clusters from the initial, 'flat-earth' symmetry. By doing so, it becomes possible to easily apply methods of linear economic dynamics to the problem and hence determine the stability of this flat-earth equilibrium.

Deviations that disturb this initial equilibrium are modelled as sinusoidal fluctuations[3] that grow and eventually establish into industrial clusters. By solving for the stability of the system after this starting point it is possible to determine whether – and how many – agglomerations will in fact form. These deviations arise naturally as a consequence of the parameters of the model – the size of the manufacturing sector in the economy; consumers' elasticity of substitution; trade costs and the presence (or absence) of industry-specific factor inputs. These subsequently impact on the frequency of the fluctuations, and result in a 'preferred frequency'.

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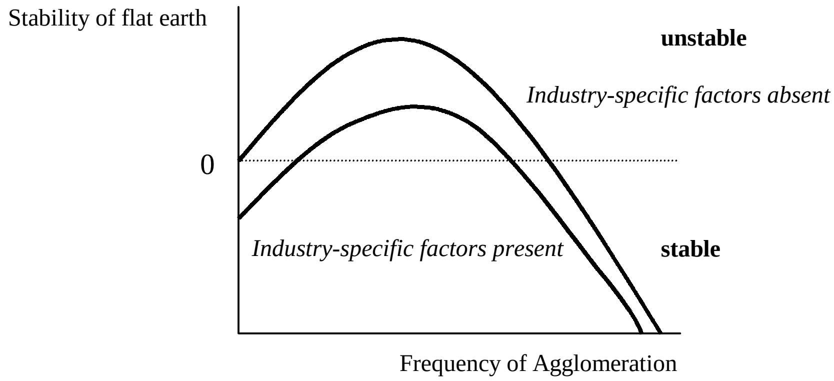
gathering, and differing languages, cultures & legal and regulatory frameworks. The importance of trade costs cannot be underestimated – see Obstfeld & Rogoff (2000).

[3] It is possible to show that such a fluctuation is in fact inherent in the solution to the model.

The preferred frequency is simply the number of agglomerations that form in a stable equilibrium. Of key interest, for the purposes of policy, are the latter two parameters of specific factors and trade costs. These shall be examined in turn.

Figure 1 illustrates a hypothetical case for the two-industry case where a simulation has been run for the case where industry-specific factors are either absent or present (to a small degree). The curves represent the stability of the flat-earth equilibrium, or, equivalently, the likelihood that industry clusters will emerge. The preferred frequency is the point where the curve attains a peak in the diagram. Below the horizontal dotted line, centrifugal forces dominate; the flat-earth equilibrium is stable and no agglomerations result. Above this line, centripetal forces are stronger; the initial equilibrium is unstable and a varying number of clusters will develop.

As can be seen, the presence of an industry-specific factor shifts this curve downwards, leading to a lesser likelihood for clusters to form. However, intermediate frequencies – not too high, not too low – will grow. This is intuitively tenable – where there are no specialised factor inputs, it is possible to locate in many different regions (and hence lead to a wider range of possible number of clusters); but where inputs are specific to the industry, there is greater motivation to pool resources to fewer locations. Therefore, although agglomerations are less likely to occur, *if they do*, only an intermediate number of clusters will emerge.

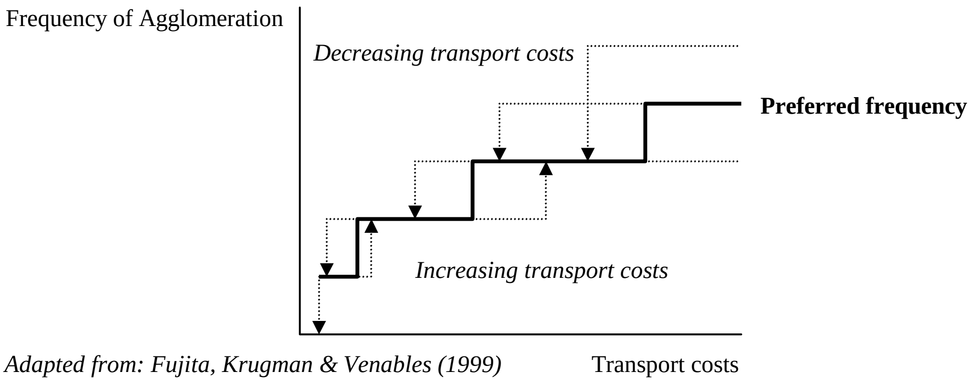


Adapted from: Fujita, Krugman & Venables (1999)

Figure 1. Effect of industry-specific factors on agglomeration

Transport costs also have an influence on the economic geography of a region. Figure 2 summarises the results of the same two-industry case, with industry-specific factors present and differing values of transport costs. The solid line represents the preferred frequency, and the dotted lines show the actual evolution of the spatial structure of the region, for the two cases of increasing and decreasing transport costs.

Most evident from is the diagram is the ‘punctuated equilibria’ nature of this evolution – long stretches of stability are interrupted by episodes of discontinuous change. This is the consequence of tensions between the circular causation that sustains the existing structure and the pressure for change that falling transport costs create. This inertia persists for some time even after the model’s parameters have changed, but eventually, a critical point is passed, and another economic geography develops.



Adapted from: Fujita, Krugman & Venables (1999)

Figure 2. Effect of transport costs on agglomeration

Notice as well that there are asymmetric pathways for either increasing or decreasing transport costs. As such, there is a considerable degree of path dependence in the evolution of the economy over time.

Beyond the absolute *number* of agglomerations that might form, what does the model imply for the spatial *location* of these agglomerations? Maintaining the two-industry case, assume that there is a 2:1 trade cost difference between industry 1 and 2. Next, consider an *overall* decrease in trade costs – such as that which might be experience due to increased economic integration. Figure 3 shows the spatial distribution of the industries, with the curves representing the concentration of industry at each location and three levels of transport costs – high, intermediate and low.

As trade costs fall, there is a move toward a lower frequency of agglomeration. This is in accordance with the analysis already presented above. Further, this frequency change is characterised by significant changes in the economic landscape. In particular, industry 2 (the lower trade cost industry) moves from occupying the core in the second panel to occupying the periphery in panel 3. Likewise, the higher trade cost industry shifts from periphery to core. Intuitively, as trade costs fall across the board, the trade costs for industry 2 become low enough such that agglomeration forces become unimportant, and in order to benefit from lower wages at the periphery, it relocates accordingly.

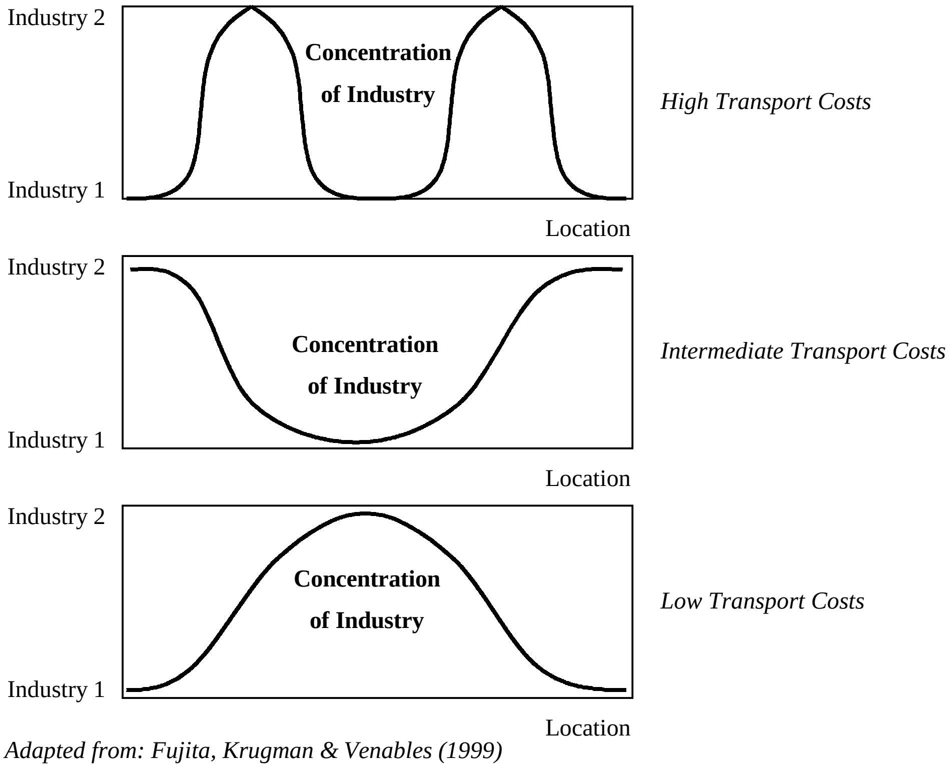


Figure 3. Effect of transport costs on location

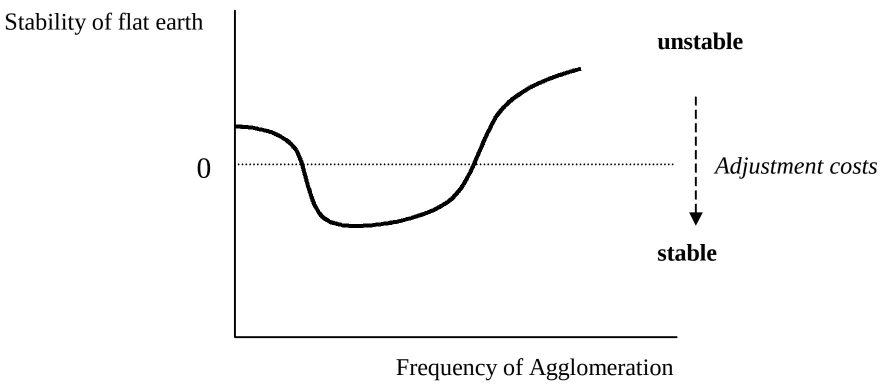
A seamless world with no trade costs

As can be inferred from the previous model, when trade costs fall to zero, all activity would either converge into a single region, or the opposite of a completely random scattering over space would result. The Quah (2000) model addresses this apparent inconsistency by introducing a factor that captures the impact of time-zone connections. This is built on a dynamic, rational expectations model consisting of forward-looking producers who maximise a present discounted value of profit flows for a single homogeneous good.

Although transport costs are negligible, other forces come into play. On the one hand, there is the centrifugal force of technology spillovers across time-zones. This spillover effect is maximised within the time-zone (although it contributes elsewhere as well, decreasing as a function of distance); as such, this encourages location at every time-zone. On the other, the costs of uprooting and planting new production facilities act as a centripetal force supporting agglomeration.

The approach used is similar to the Turing (1952) analysis of the previous model. Similarly, the stability of the flat earth equilibrium depends on the interaction of these two forces. Producers' choices of location are influenced by the elasticity of factor substitution, the strength of time-zone spillover effects and the 'stickiness' of factor inputs. The higher is this adjustment cost parameter – the only parameter of interest to policy – the more sluggish is the producers' response to changes in location that would maximise returns.

This implies that as adjustment costs increase, the probability that industry agglomerates into clusters fall. However, as in the case with non-zero trade costs, only intermediate ranges of adjustment costs will yield distinct periodicities or clusters. The explanation above can be made compatible with the foregoing analysis by viewing this stickiness of factor inputs as the presence of specific factors that incur significant relocation costs. However, this definition can also be expanded to include more general, immeasurable factors, such as the quality of the living environment (affecting labour) or the business environment (affecting capital). The effect of adjustment costs on agglomeration is illustrated Figure 4.



Adapted from: Quah (2000)

Figure 4. Effect of adjustment costs on agglomeration

It is useful to examine the intermediate adjustment cost case in greater detail. Upon the introduction of a disturbance, the uniform spatial density twists itself into a form such that waveforms, representing clusters, appear. As the underlying geography is homogenous, the nature of the disturbance is the sole determinant of where peaks and troughs appear (subject, of course, to the economic parameters discussed earlier).

Cycles such as these always arise in space, and these cycles may or may not have corresponding cycles in time. However, all waveforms will eventually converge toward the uniform flat-earth steady state. So long as the system is continually perturbed by disturbances, *only* clusters of economic activity are observed. More likely, though, is the situation where clusters occur on different points in space through time, just as industrial clusters wax and wane in the course of economic history. Figure 5 shows the emergence of cycles in space caused by local perturbations.

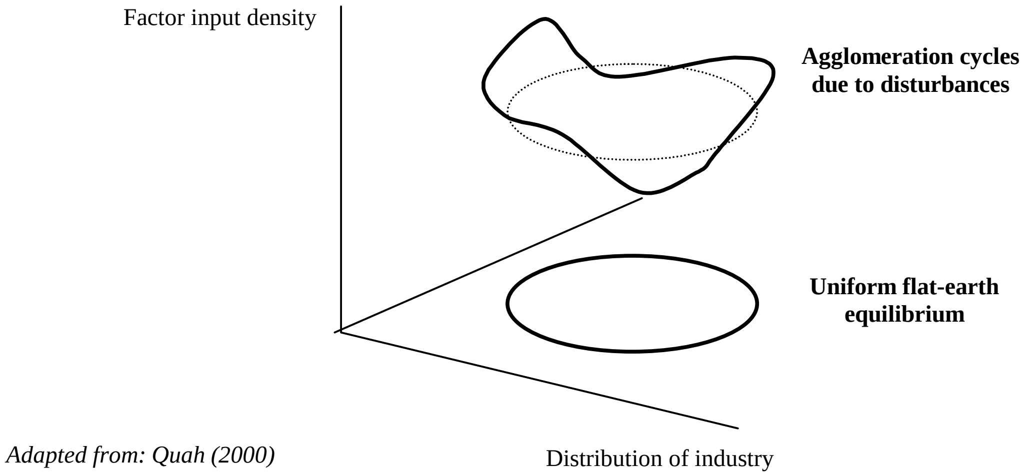


Figure 5. Effect of disturbances on agglomeration

Cluster analysis and competition effects

To concentration of these quantitative models on the agglomeration economies of linkages neglects several important qualitative variables. Porter (1998) discusses these additional influences in the context of competitive advantages gained through location in industrial clusters. The analytical framework for which location influences productivity and productivity growth is depicted in the so-called Porter (1990) diamond model, and is reproduced in Figure 6.

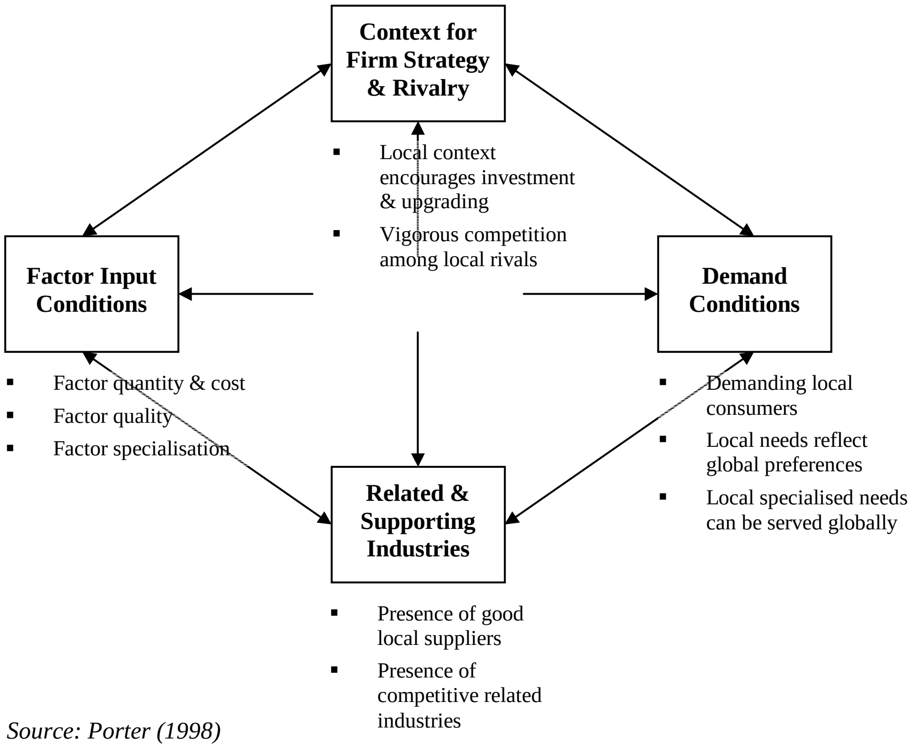


Figure 6. Porter diamond model of locational competitive advantage

Factor input conditions include tangible assets, such as physical infrastructure, and intangible assets like information and the legal framework. The context for firm strategy and rivalry encompass aspects such as the climate for investment as well as local policies that affect rivalry. Demand conditions can have profound effects on whether firms move from imitative, low-quality products and services to competing based on differentiation. Finally, and most importantly, related industries are the key facet of the diamond that act to encourage cluster formation and growth.

The model argues that the quality of the business environment is of paramount importance in determining the level of sophistication and productivity by which business compete; further, the cluster specific aspects of the business environment are deemed to be more decisive. In particular, clusters exert strong influences on productivity, innovation (and therefore productivity growth) and new business formation that supports innovation and subsequently expands the cluster (Porter 1998).

Productivity is improved in clusters due to increased access to specialised factor inputs; enhanced access to information; facilitated complementarities between the activities of cluster participants; greater access to institutions and public goods and improved incentives and performance management. The more dynamic advantages gleaned from clusters accrue to productivity growth, and such gains are based on knowledge spillovers[4]; lower costs of innovation and experimentation and the pressure to innovate. New business formation is spurred on by the improved information about opportunities and lower barriers to entry (and exit) in a cluster. Moreover, new business formation in a cluster can play an important feedback role to innovation, as these new companies pick up the slack in innovation left behind by larger firms – indeed, spin-off firms often receive the blessing of their parent corporation[5].

In light of policy, the role of government in the larger economy vis-à-vis industrial clusters involves four key areas: first, the maintenance of macroeconomic and political stability; second, the improvement of microeconomic capacity; third, the establishment of

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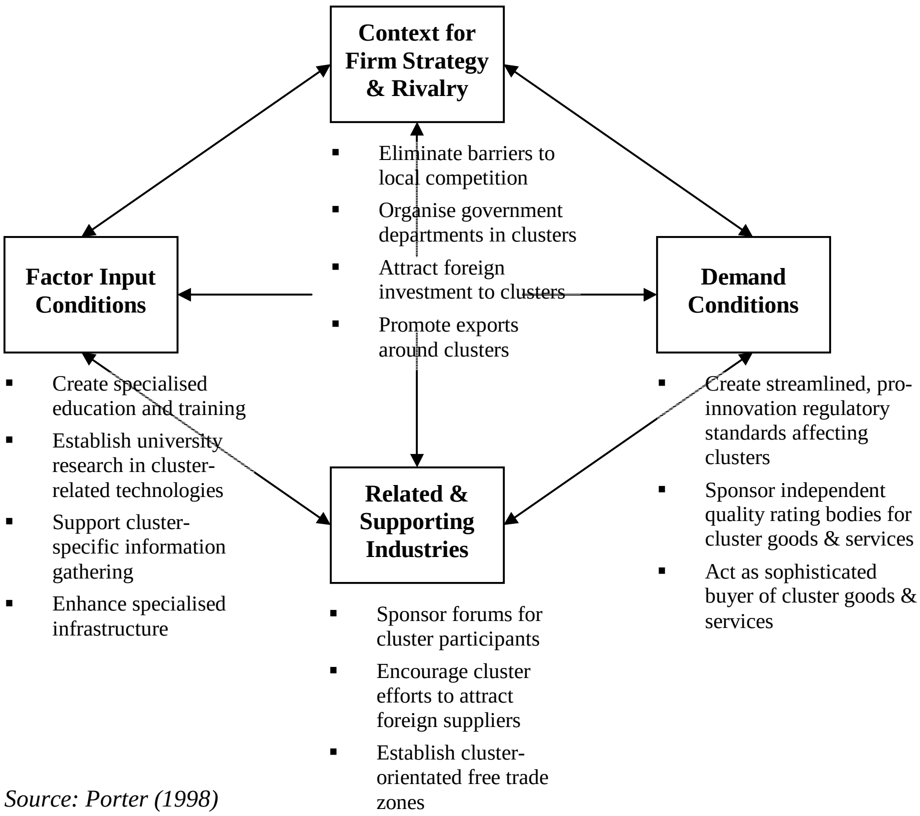
[4] Some empirical work exists on the relationship between knowledge spillovers and geographic location. See Audrestsch & Feldman (1996) and Jaffe, Trajtenberg & Henderson (1993). However, to our understanding, there has been no formal expression of knowledge spillovers in new economic geography models.

[5] The strong relationship between innovation and growth has been the centre of focus for recent research in endogenous growth theory. An example of work in this field with a more international flavour is Grossman & Helpman (1991).

microeconomic rules and incentives for competition and last, the facilitation of cluster development and upgrading. Although the first three aspects of government policy clearly impact different parts of the diamond, the final role which emphasises the government's role in cluster development is of greatest interest, and the discussion will restrict itself to its exposition.

As a preliminary, the distinction between a cluster-based approach to economic development versus industrial policy must be made. Industrial policy – the targeting of specific industries for growth and development favoured by many East Asian economies – leads to a zero-sum view of international competition and consequently a strategic view of trade policy. In contrast, cluster theory rests on a broader, more dynamic view of competition that emphasises growth in productivity; as such, it advocates the development of *all* clusters, not just selected ones. The implications of this stance are that foreign imports and firms are viewed as important contributors to agglomeration externalities and therefore a positive sum view of competition and trade results.



Source: Porter (1998)

Figure 7. Government influences on Porter diamond model

Figure 7 summarises the impact of government influences on cluster upgrading in the context of the diamond model.

III. ICT industry development in Singapore & its links with ASEAN

The ICT industry in Singapore has been a prominent feature of the economic landscape since the late 1980s, although the manufacturing base in electronics traces its roots to as early as the mid-1960s. The discussion will revolve around three inter-related aspects: ICT goods, ICT services and ICT infrastructure.

ICT goods industry

The ICT goods industry in Singapore – broadly defined to be the electronics goods industry – currently contributes to more than half of Singapore's total manufacturing output (EDB 2000a). The initial phases of Singapore's physical capital development involved establishing an ICT goods manufacturing base for MNCs from the mid-1960s to the late-1970s, followed by the rapid diffusion of computerisation from the late-1970s to the late-1980s which saw Singapore becoming a major manufacturing site for computers and peripherals (Wong 1997a).

Significant in this second phase is the shift in focus from basic semiconductor assembly to more complex products, including testing, as well as the emergence of a critical mass of local electronics supporting industries, especially in printed circuit board assembly and precision engineering (Wong 1992). Thus, the trend reflecting a decline of semiconductor assembly and the subsequent rise of more specialised electronics goods is clear.

The third phase of the ICT goods industry's evolution started in the late-1980s and continued on till the mid-1990s. The period experienced further technological upgrading and expansion in the industry, with another shift in concentration, from the more skill-intensive specialised electronic goods to technology-intensive sectors, such as semiconductor wafer fabrication, computer printers, telecommunication equipment and hard-disk drive manufacturing. At the same time, supporting industries continued to develop and grow (Wong 1997, 1998). Again, the trend is evident: a changing economic landscape, where the decline of skill-intensive ICT goods manufacturing is accompanied by a rise in technology-intensive ICT goods, with a relocation of these declining industries to regional areas such as Malaysia and Indonesia.

In the most recent phase from the late 1990s to the present, the information technology and electronics industry in Singapore remains as a mainstay in its small economy. In the electronics industry, Singapore possesses core capabilities in digitisation, wireless technology, miniaturisation, automation, human interface technology, product intelligence, product management and, more recently, memory wafer fabrication and application-specific integrated circuit (ASIC) production. The semiconductor industry has been involved in integrated circuit design, automated assembly and testing, metal injection moulding and high-density multi-layer printed circuit board (PCB) manufacture (Low 2000). This is an extremely diverse range of production fronts, but are similar in the respect that many of them involve interactions between scientific disciplines, such as computer science, engineering and artificial intelligence. The focus highlighted by the Economic Development Board (EDB) is that of six 'H's – high value-added, high growth, high renewal, high precision, high reliability and human-friendly characteristics. As a result, the traditional, more narrowly specialised areas of ICT goods manufacture such as are no longer at the forefront of the economy's manufacturing base. Despite the wider focus, Singapore's production capability in ICT is comparable to that of Taiwan or South Korea. Under the Industry 21 Masterplan, the aim is to position Singapore as a world-class electronics hub, generating S$150 billion worth of output by the year 2010 and achieving a compounded annual growth rate (CAGR) of 8 percent (EDB 2000b)[6].

In terms of human capital, labour trends in the ICT goods industry have been a reflection of the changes in the focus of ICT goods production. First-phase workers in the ICT goods industry were mostly unskilled labour that was in abundant supply; by the end of the second phase at the end of the late-1980s, there had been a definite shift toward skilled labour (Wong 1998). This is evidenced by the increasing numbers of technically-trained manpower produced by the tertiary education institutions: a sharp rise from 2,200 in the period 1970-79 to 3,500 between 1980-84 and as many as 7,000 between 1985-89 (Wong 2001).

As Singapore moved into the 1990s, the continued expansion of a technology-trained workforce had led to further increases in technical manpower from tertiary institutions – rising to 9,360 between 1990-93 and then to 11,070 in the period 1994-97 (Wong 2001). As of 2000, the number of workers employed by the electronics industry is in the excess of 114,000. This has not been an accident but a conscious policy orientation of the government to develop, nurture and expand the technology-trained workforce.

The Singapore government, as a consumer, has also played a key role in engaging ICT. The public sector has always been at the forefront of computerisation efforts, from the Civil Service Computerisation Programme (CSCP) in the early 1980s to the aggressive expansion of computer systems in government departments in the late 1980s under the National IT Plan (NITP) to the pervasive application of computers and its applications in all areas of

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[6] Much of this will depend on the electronics cycle in Singapore, which does not have a fixed duration or amplitude, although reasonable analysis would estimate a cycle every four to five years. The next peak in demand would be due in 2004/05 (Abeysinghe & Wilson 2001). Also see Abeysinghe (1996).

government through the 1990s (under the IT2000 plan). Table 1 summarises several key statistics of Singapore's ICT goods industry.

Intra-ASEAN bilateral trade in ICT goods between Singapore and ASEAN is significant, and has been increasing in recent years. Table 2 shows the quantity and value of intra-ASEAN trade in ICT goods between 1990 and 1999. Three aspects of the table merit attention. First, with the exception Cambodia, all other ASEAN countries represented have experienced a net increase in the value of ICT goods traded from 1990 to 1999. Second, regional trading partners account for a large part of bilateral ICT goods trade with Singapore. If other regional Northeast Asian countries are included, then intra-regional trade accounts for almost all of Singapore's top 10 bilateral trading links. Last, Indonesia is conspicuous in its absence. This is primarily because of the absence of statistics on bilateral trade links between Singapore and Indonesia. This is exacerbated by the extremely small size of trade in ICT goods for Indonesia in general – in 1998, imports and exports of computer equipment totalled US$200,792 and trade in telecommunications equipment US$1,096,829. This accounts for only approximately 1% and 4.8% of the region's trade in these products, respectively (ITC 2000). Tariffs rates on machinery and electrical appliances were 6.0 percent for ASEAN-6 and 5.9 percent for the whole of ASEAN in 1996. In 2000, this fell to 3.5 percent for both the ASEAN-6 and ASEAN-10. Under the Common Effective Preferential Tariff (CEPT) scheme, this should fall to 2.7 by 2003 (ASEAN Secretariat 2000).

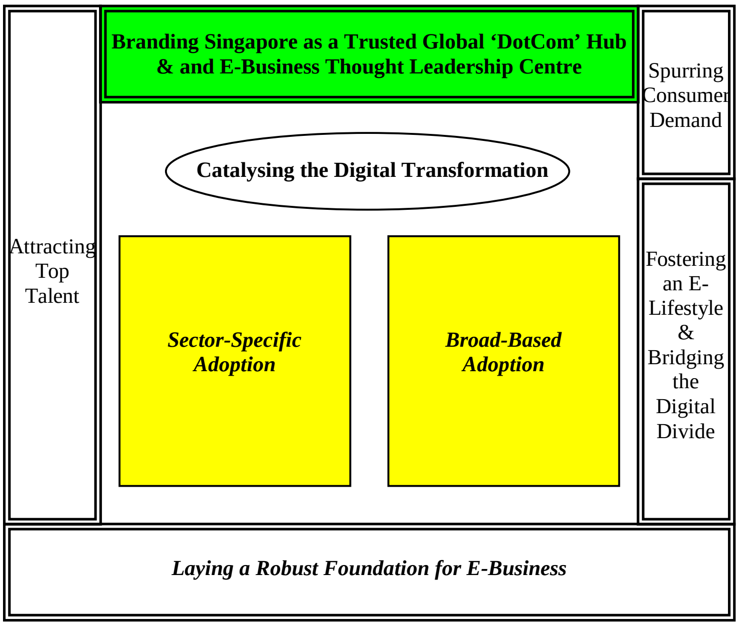
ICT services industry

For the purposes of expository ease, the term ICT services industry is taken to include software, content and ICT services – items that involve little or no trade cost, or so-called 'weightless' economic items. In the early stages of Singapore's industrial development, ICT services industry did not feature prominently, if at all, in the economy. However, with the rapid diffusion of computerisation through to the 1990s, this sector began to come into its own, such that by the early 1990s there was a growing recognition of the importance of an ICT services industry. This was most evident in the IT2000 plan, which had, as a strategic thrust, the aim of enhancing the potential of individuals through skills, creativity and knowledge (NCB 1992).

As ICT services remain as a new and potentially underdeveloped area in general, Singapore has concentrated much of its Infocomm 21 policies on building up this industry. This was to piggyback on the national information infrastructure (NII) that was the emphasis of ICT policy from the late 1980s to the mid 1990s. The pervasiveness of ICT in even the more lowtech sectors such as retail and transport (Teo & Lim 1998) has also meant that it has become difficult to disentangle ICT services from more traditional non-ICT services.

The ICT services industry has two primary areas of focus: that of software, content and intellectual property provision, and that of electronic commerce. In the first category are essentially weightless goods with high sunk costs but virtually negligible marginal costs. In the second, the virtual storefront may or may not be the only transaction interface; but often, brick and mortar physical capital is still required for storage and transport purposes, and in that sense they are not completely weightless goods. Nonetheless, since an electronic storefront providing e-commerce still involves service provision (through the channels of electronic marketing, e-commerce application specialists, sales and distribution services and management), these areas will be discussed as ICT services under the banner of e-commerce.

Under the first category, the government aims to increase its competitiveness through: jumpstarting the development and growth of an interactive broadband and multimedia industry (IBBMM); increasing the level of innovation in key growth areas; and fostering strategic international alliances and partnerships. Through these methods, it aims to double infocomm revenues to S$40 billion by 2005, increase the export component of infocomm revenues to 70% (from the current 50%) and creating a thriving 'infocomm ecosystem' of IBBMM service providers and end-users (IDA 2000).



Source: IDA (2000)

Figure 8. Framework for electronic commerce in Singapore

Figure 8 sums up the framework for the strategy for developing e-commerce in Singapore. At its foundation is the infrastructure services and setting (this is discussed in the next subsection). The other aspects of e-commerce policy are to spur consumer online spending, enhance e-business readiness and catalysing the digital transformation through encouraging broad-based community usage of e-commerce and more sector-specific cluster policy to encourage e-commerce adoption[7].

Going into the future, policy for developing human capital will increasingly favour the recruitment of ICT service professionals as well as more electronic methods of training and education. Three strategic areas stated in the Infocomm 21 Masterplan are to: first, enhance the environment for an Internet-savvy workforce; second, to attract and retain international ICT service talents; and third, to establish Singapore as a centre for e-learning. The desired outcome is to attain 250,000 infocomm workers[8], up from the current pool of 93,000, such that it will comprise about 10 percent of the workforce by 2010 (IDA 2000).

Intra-regional trade in ASEAN in ICT services, unfortunately, does not present readily available statistics. Anecdotal data and case studies, however, suggest that the value and volume of ICT service trade is small but growing. e-ASEAN initiatives to form an ASEAN ICT job bank and targets to improve and enhance the environment for ICT in the regional economies and co-operation in human resource capabilities and development should increase the strength of these trade linkages.

ICT infrastructure

The ICT infrastructure in Singapore consists of not just physical infrastructure but – perhaps more importantly – institutional and environmental infrastructure. The physical ICT infrastructure will be centred on the IBBMM and mobile wireless network, which is the

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[7] The Boston Consulting Group (1999) places Singapore as one of the top 10 countries in the Asia Pacific for consumer online spending and the Economist Intelligence Unit (2000) ranks Singapore as the 1st in Asia for e-business readiness.

[8] The official definition of infocomm manpower is “a person engaged primarily in infocomm-related work either in an IT supplier, telecommunication vendor or user organisation (including government). The work of the person may include (a) development, distribution, implementation, support and operation of telecommunications, computer hardware/software and multimedia contents; (b) provision of information services to end-users; (c) dissemination of IT knowledge and skills; or (d) management of the above processes” (IDA 1999). These all fall within the definition used earlier to describe the ICT services industry.

successor of the more narrowly-focussed Singapore ONE network[9], and the narrowband component of the NII. Institutional factors which affect the business environment would include the legal and regulatory structure present in the economy as well as the degree to which the economy has matured to possess a knowledge base.

The proposal for an IBBMM and mobile wireless network rests on the report by a consortia of private and public academics, researchers and industry players. The aim is for a pervasive infocommunications network in Singapore that would support high-speed, wireless data access for Singaporeans by 2005 (Infocomm Technology Roadmap 2000). This would be realised through xDSL and cable modem technologies, optical fibre installations, fixed wireless technologies and 3G mobile networks.

Further, the NII also includes a narrowband component. The key applications in the existing narrowband NII is undoubtedly the national system for electronic data interchange (EDI) which began with TradeNet in 1989, and has rapidly grown to include CoreNet, PortNet and other EDIs[10] (Teo & Lim 1998). Another aspect of the NII involves cashless transactions. The GIRO service allows account holders of banks to place standing orders for automatic approval for transfer of funds to chosen merchants or government bodies, which greatly simplifies routine payments and saves on manpower, time and paper work; also, cash flow accounting is also made more predictable and timely. The complementary Network for Electronic Transfer System (NETS) allows holders of bankcards to authorise electronic fund transfers at point of sale through keying in the account holder's PIN into a handheld unit. Payment by NETS in Singapore has become as commonplace as payment by credit and debit cards.

Singapore's legal, regulatory and enforcement framework was brought in line with international standards and models in 1997. In addition to the existing sound legal system that governs the area of ICT goods, additional regulatory changes and supplements were made to enhance ICT service provision. These regulatory changes involve the enactment of an Electronic Transactions Act, amendments to the Computer Misuse Act, as well as other minor amendments to other acts (such as the Copyright Act) and rules of court. These were all designed to promote and enhance trust and confidence in e-commerce and ICT services in general and include: a

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[9] In a sense, the Singapore ONE network, which is domestic, can be considered a subset of the wider IBBMM network, which is global. The IBBMM network was nonetheless modelled after the successful Singapore ONE.

[10] TradeNet electronically links up parties engaged in trade, CoreNet serves the construction & real estate communicty and PortNet, the shipping community. Other EDIs include LawNet, MediNet and TechNet for the legal, medical and technical fraternities, respectively.

commercial code to support e-commerce transactions, provision of a public key infrastructure, changes to strengthen local intellectual property laws.

In the regulatory arena, the Singapore government adopted a radical liberalisation and consolidation policy that led to a revised, accelerated schedule for telecommunications liberalisation and a convergence of information technology, broadcasting and communications media. During this period, service operators' fees collapsed as former licensing restrictions were lifted and potential entrants entered the market. Although the scene remained dominated by large, often government-linked firms such as SingTel and major business consortia like StarHub, room opened up at the bottom for SMEs to sub-licence bandwidth and offer low-priced, niche-market services. As a result, the increased competition led to falls in the prices of international calling services, mobile phone charges and Internet access charges.

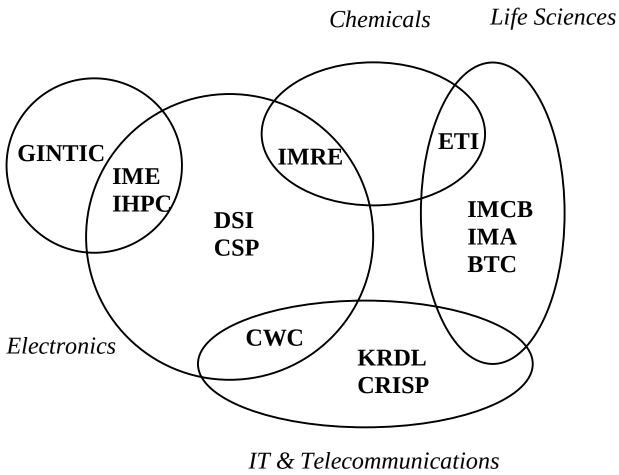
The liberalisation also extended to more traditional mass media. Coaxial cable access has been installed in a large number of homes over the island, and the existing optical fibre coverage of Singapore homes has risen to over 90 percent. Also, a host of leading satellite content providers has set up regional centres in Singapore, including MNCs such as HBO, ESPN, MTV and the Discovery Channel. The newspaper industry has also experienced renewed competition, with the introduction of more newspapers, such as Streats and Today.

The area of public policy related to fostering a positive knowledge-based economy is the country’s Science and Technology (S&T) policy, or National Innovation System (NIS). After an initial phase of technology importation pre-1990, a National Technology Plan (NTP) was formulated over 1991-1995, followed by a more ambitious National Science and Technology Plan (NSTP) over 1996-2000, both under the auspices of the National Science & Technology Board (NSTB 1991, 1996). Under these programmes, R&D activity rose correspondingly, attaining a CAGR of 18.6 percent over the last 10 years. Related R&D statistics are shown in Table 3.

This is admirable when considered in the context that prior to this period, R&D expenditure was a minuscule part of national GDP. For example, in 1978, Gross Expenditure on Research and Development (GERD) was as little as S$37.8 million, or 0.21 percent of GDP. Interestingly, much of this R&D effort was spearheaded by the private sector. Of the organisations performing R&D during this time, the overwhelming majority was private sector efforts. In 1990, the private sector had 266 R&D organisations, out of a total of 292; up till 1997, this ratio was 508 out of 543 (Wong 2001). It should be noted, however, that in terms of expenditure, the spread was more even, with the private sector taking a share of about 60 percent of total GERD.

There has also been a major effort towards fostering domestic technopreneurship through the creation of a favourable ‘technopreneurial environment’. Instigated by the Asian financial crisis, the Singapore government has begun to re-examine the traditional role of importing technological and R&D knowledge from foreign sources and to instead look inward at developing local talent. The NSTB was restructured to focus on 6 key thrusts, all aligned toward developing ICT capability and technopreneurship.

These thrusts were to: further promote science and technology to students, professionals and the public via growing technopreneurial businesses; develop a conducive environment for technopreneurship; develop an investment infrastructure for new technology enterprises; develop manpower for R&D and technopreneurship; establish operations in international high-technology nodes and strengthen the technology infrastructure. A website[11] geared toward preparing a potential enterprise for the challenges of technopreneurship was set up; tertiary institutions have been restructured to emphasise more laboratory work; and public research institutes and centres (RICs) have been positioned to act as a bridge between the basic research produced by universities and the applied research carried out by the private sector. Figure 9 illustrates the structure of public RICs and the respective industry clusters that they support.



Key:

BTC – Bioprocessing Technology Centre
CRISP – Centre for Remote Imaging, Sensing & Processing
CSP – Centre for Signal Processing
CWC – Centre for Wireless Communication
DSI – Data Storage Institute
ETI – Environmental Technology Institute
GINTIC – Gintic Institute of Manufacturing Technology
IMRE – Institute of Materials Research & Engineering
IME – Institute of Microelectronics
IMA – Institute of Molecular Agrobiology
IMCB – Institute of Molecular & Cell Biology
KRDL – Kent Ridge Digital Labs
IHPC – Institute of High Performance Computing

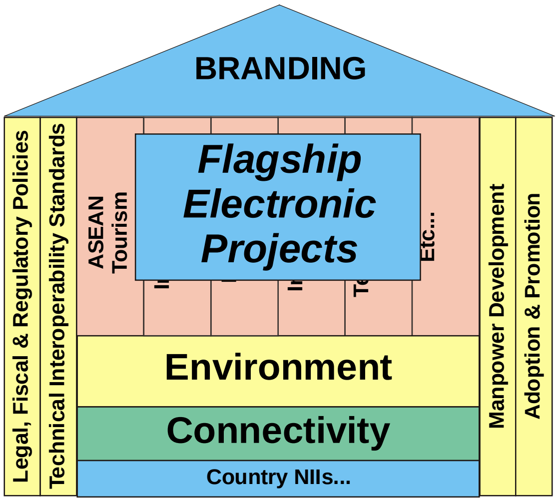
Source: NSTB (2000)

Figure 9. Public Research Institutes & Centres

The e-ASEAN agreement has also included a proposal for an ASEAN Information Infrastructure (AII) that is to build on the information infrastructure plans of member countries, such as Indonesia’s Nusantara 21, Malaysia’s Multimedia Supercorridor and

[11] http://www.techsingapore.com.sg

Singapore's NII. This is expected to increase efficiency in information and technology transfer across ASEAN nations. Through this initiative, e-ASEAN hopes to promote increased connectivity between ASEAN and key global economies, create a positive ICT environment, attract foreign investment in ICT into ASEAN, develop regional human resources and harmonise policies, standards and regulations. Proposed applications for the AII include an ASEAN Trade Link, an ASEAN Tourism Portal, an ASEAN Educational Network and an ASEAN-wide ICT job bank. The (somewhat) ambitious target is to attain all the key conceptual pillars by 2005 (IT Private Sector Core Group 1999; Working Group on AII 1999). This is summarised in Figure 10.



Source: Summary Report on the Feasibility of the AII

Figure 10. Conceptual Pillars of e-ASEAN

Analysis

The changing economic landscape and the role of Singapore as an industrial core for high-technology industries has been in accord with the theories presented in section II. On the whole, much, although not all of the changes in the economic geography of Singapore and the wider ASEAN region are unsurprising in the light of the various theories presented. Furthermore, the success of these theories in explaining the observed economic phenomena of the past gives credence to the implications drawn from the theory for the future. Finally, this gives weight to the policy prescriptions to be presented, and clarifies the role of public policy in this respect.

Representations of past developments

Section III has presented a historical overview of the changing economic landscape of Singapore's ICT goods industry. There have clearly been rises and ebbs of particular types of

ICT goods, which have been broadly segregated into four phases. When understood as natural relocations of industries as a result of falling trade costs (due to the establishment of ASEAN which provided closer links between countries and just a fall in the overall costs of transportation in general), the shifts in the locus of the ICT goods industry in both Singapore and the region become more explicable. Lower trade-cost industries such as basic semiconductor assembly have moved from the core in Singapore to peripheral sites in lower-wage countries in the region, whilst higher trade-cost industries like high-density multi-layer PCBs have located themselves in Singapore[12]. It is therefore important to recognise that the terms 'core' and 'periphery' do not necessarily imply permanence or even importance. The implication of a secular decline in trade costs might first create a region divided between the wealthy core and poorer periphery, but the very same process causes that division to collapse. Hence, both core and periphery countries benefit from the economic decisions of firms on their spatial location over time, when trade costs fall.

The change in labour force utilisation is a clear sign that Singapore has worked to provide industry-specific factor inputs and conducive factor input conditions, and as a result, has created the necessary conditions for attaining the position of a regional ICT goods hub. It has been shown that the focus of this role as a hub has evolved according to the changing economic geography, in accordance to declining transport costs and general economic conditions. Part of the reason why Singapore has maintained this hub status is precisely because it has provided specialised inputs and is willing to acknowledge changes in its comparative advantage, while providing other favourable factor input conditions such as an increasingly technologically-trained workforce. More recently, this shift has involved a decline in manpower in electronic manufacturing and a rise in more knowledge-based industries.

In addition, the government has generated demand conditions that have positively fed back to the high-technology goods cluster. It has been a pre-emptive, sophisticated purchaser of ICT goods, hence creating favourable demand conditions through demonstration effects that reduced private sector uncertainty surrounding ICT goods and stimulated their early adoption of ICT. As a significant buyer, it has also encouraged the fledgling ICT cluster in its growth.

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[12] It can be reasoned that more highly differentiated goods (such as complex PCBs) incur higher trade costs as opposed to less differentiated goods (such as basic semiconductors) due to the greater complexity of gathering information about these more highly differentiated goods and the higher costs of ancillary services such as insurance and product standards control. This is an extension of the argument presented by Rauch (1996), who applied the reasoning to homogenous and differentiated products.

The strong trade links in ICT goods in the region suggest that the model can in fact be used as a basis for studying past changes in the economic geography of ASEAN. The inextricable link of ASEAN nations in so many other aspects of economic co-operation is further reinforced by the mutual dependence that trade in ICT goods demonstrate. As argued above, this need not be viewed as a zero-sum game but rather as one in which the entire region benefits from the economic engine created by the ICT revolution.

In the same manner, the previous section has also outlined the gradual increase in ICT service activity in Singapore. Increased economic integration in ASEAN, together with the e-ASEAN agreement, means that the costs of adjustment for establishing and relocating ICT services industries falls, and so, clusters can be expected to form. This has been precisely the case for ASEAN, and Singapore has seen itself grow in importance as a centre of ICT service activity. Acting in opposition to this centrifugal force supporting agglomeration has been the centripetal force of time-zone spillover effects. One can venture to suggest that the longitudinal position in which Singapore falls in is a happy coincidence. Geographically, Singapore is in the centre of the ASEAN economic zone, and its location between the other significant ICT service clusters of Japan (Tsukuba) and India (Bengalore) indicate that the economic geography tensions find an equilibrium in Singapore.

ICT service trade links, although nascent, has grown over the recent past and certain aspects of the e-ASEAN initiative would submit that these will continue to grow. For example, the ASEAN Trade Link would undoubtedly be a driver for further growth in the ICT service sector, as the link provides not only the benefits from market making activities but also back-office support operations such as online trade clearances. Again, these are additional signs that trade costs will fall further as ASEAN integration proceeds, and especially so for the ICT service sector.

These basic quantitative conditions are further supplemented by several qualitative factors that are present in Singapore. Again, there have been positive demand conditions due to both the active engagement of government bodies in ICT service utilisation as well as Singapore’s strong financial services industry, which is an intensive user these services. Indeed, the financial services industry has become so ICT-heavy that a wider cluster would possibly comprise of both ICT services and financial services. This creates a self-reinforcing cluster of related and supporting industries. Likewise, factor input conditions have continued to be very favourable, as evidenced by the stance of ICT manpower development policy as well as the policy towards the infocomm service industry in general. The narrow and broadband aspects of the NII have provided excellent support for clusters, and a sound legal system and a deregulated ICT scene have set a positive context for firm strategy and rivalry.

As deeper economic integration proceeds and adjustment costs fall, a change in the regional economic landscape will depend on whether these costs fall to such as extent as to justify location in even more centres. If these costs do fall, as they might be expected to, it is likely that the ICT services industry will then relocate to a far more even distribution across the earth, i.e. attain a flat-earth equilibrium that consists of many small pockets of ICT service industries.

The Internet is already showing that this is a more than likely scenario. E-commerce on the Internet is no longer constrained by the traditional cluster boundaries. It has become just as possible for small operators located in the non-traditional areas (such as Antigua and Costa Rica[13]) to provide ICT services to its clients as it is for larger players situated in major metropolitan capitals (Silicon Valley) to do so. The limits of physical and geographical space will gradually erode and the testimony of e-commerce activity on the Internet is but a foretaste of the future economic geography.

Nevertheless, in the short to medium term, a host of qualitative factors continues to work towards Singapore's advantage and as a result, cluster analysis methods would suggest that the ICT goods and services industry would continue to use Singapore as a hub. The solid legal framework and supporting ICT infrastructure – both in terms of the physical IBBMM network as well as knowledge-based S&T environment – will be attractive for players, which include both the large, multinational corporations as well as smaller domestic (and possibly regional) technopreneurial start-ups. The positive externalities gained from static productivity gains and dynamic innovation benefits continue to be found in Singapore due to the existence of these key institutional and environmental factors, and as discussed in section II, these impact on new business formation and the cluster becomes self-reinforcing.

The increased integration of national information structures through the AII is a positive step that is expected to yield returns in terms of increased knowledge spillovers, the generation of thicker markets for both factor inputs such as labour and foreign capital as well as demand, both internal (through increased intra-ASEAN e-commerce) and external (through stronger ties with extra-ASEAN networks). The institutional environment will also receive a boost through the decision to harmonise ICT policies, regulations and standards. Whilst achieving this goal by 2005 this is admittedly a difficult task, ICT has traditionally been a common driving force and has often cut through deep bureaucracies relatively quickly. The increased

[13] The Caribbean islands, other than being attractive locations for winter getaways, are also popular locations for Internet gambling operators due to their liberal tax systems. See Sinclair (2001).

economic integration in this sector also bodes will for future endeavours to harmonise the institutional environments in ASEAN in other, possibly more protected, sectors.

Implications for future policy

With increased economic integration through the e-ASEAN agreement, there is expected to be a liberalisation of trade in ICT products and services, with progressive liberalisation in three tranches, with the tranches taking effect in January 2003, 2004 and 2005[14]. This would suggest that trade costs are further expected to fall; consequently, the economic geography of the distribution of ICT goods industries might change (subject, of course, to a new punctuated equilibrium developing).

Rather than chase fashionable technologies or prestigious projects, governments should work at developing the clusters that have already established themselves in their countries, and let market forces determine which industry clusters are best located in their economies. Far from implying a totally hands-off approach, it instead suggests one of cautious interventionism, an approach that does not involved arbitrary choices such as 'picking winners' but rather one that sees the primary role of government as a facilitator. If the perception of the government is that a particular area – either ICT goods or services – warrants involvement, it should do so, as far as possible, as a market participant.

The possible flat-earth equilibrium for the ICT services industry that would arise as a consequence of falls in adjustment costs would strongly suggest that ASEAN governments should, in the medium- to long- run, seek to enhance the supporting institutions and general infrastructure for ICT service delivery. Beyond the clear need to invest in a national information infrastructure that would accommodate any future moves in this direction, governments need to ensure that R&D capabilities as well as S&T policy is flexible enough to play a larger role in the economic activities of the country. Here, the example provided by Singapore in its domestic approach to its ICT services industry can be a valuable case study and allow these countries to hasten and possibly even leapfrog the technological catch-up process.

There would also be the need to re-examine fiscal policy. As ICT services become more pervasive and the Internet becomes the medium of choice for commercial trade and activity, tax jurisdictions that are overbearing will be punished by the market, as they seek areas that

[14] e-ASEAN Framework Agreement, Article 6.

allow greater tax relief. Whereas tax can (and probably will) continue to be levied on physical ICT goods, virtual ICT services will continue to escape comprehensive taxation, and policymakers will need to response appropriately. Unless tax revenue is channelled toward the provision of infrastructural service unavailable in other tax jurisdictions, the low costs of relocation will lead these high-technology service firms to move to the next, lower-cost location.

All said, possibly the most crucial function of government would involve creating a favourable institutional framework for enhancing comparative and competitive advantage. The importance of these areas cannot be underestimated, as historical fact and, more recently, economic theory has proven time and again that institutions *do* matter.

What practical steps would this entail for policymakers? Obviously, before any ICT-specific institutional policies are enacted, basic deficiencies need to be corrected. There is little need for a comprehensive intellectual property and e-commerce law if the legal fraternity in the country has little will for enforcement. Similarly, before looking to set up a high-technology industrial park, producers providing key goods and services such as clean water and proper housing should exist. With those preconditions satisfied, the policymaker has more options under his belt. As mentioned, there is no need to 'pick winners' – if the fundamental economic environment is sound and stable, the constantly evolving economic geography will ensure that industries will eventually locate in these economies to exploit differences in wages, costs, comparative and competitive advantage. One can even imagine clusters forming in economies that might not contain industries providing all the necessary pre-requisites for the manufacture of certain ICT goods, so long as these economies are willing to open up trade linkages and engage in a pro-free trade policy. With low trade costs, importing intermediate factors of production will become a far easier and feasible possibility.

IV. Conclusion

This paper has sought to provide an understanding of the aspirations of Singapore to attain the status of a regional hub for ICT goods and services. Here, the definition of a 'hub' should not be confused with any imperialistic notions; rather, as the cutting-edge research from the field of the new economic geography clearly shows, hubs are natural phenomena that arise due to particular conditions such as the parameters of the economy and the economy's qualitative characteristics. Furthermore, the economic landscape of a region is liable to continuous change, and as discussed, this is not a necessary cause of particular policy but rather due to the decisions of economic actors as conditions change. These relocations are both necessary and beneficial to economic efficiency in general and all economies in the region in particular.

What is important, then, for the policymaker is to ensure a good institutional infrastructure, one which supports strong clusters and encourages the growth and development of promising ones, rather than picking specific ‘winners’.

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Appendix

Description	*1990*	*1995*	*1999*
Output (million $) *	27,878	57,873	68,719
▪ Computers	1,058	9,477	10,221
▪ Disc drives	7,655	13,899	18,924
▪ Computer peripherals	3,420	101	N/A
▪ Communication equipment	1,354	1,914	3,640
▪ Printed circuit boards	2,909	2,930	1,143
▪ Semiconductors	3,227	48	9,885
▪ Wafer fabrication & ICs	N/A	1,153	4,464
Value added (million $)	7,717	11,988	15,234
Sales (million $)	28,141	57,793	68,500
▪ Direct exports	24,027	45,161	53,125
Workers	122,797	126,891	105,826
Remuneration (million $)	2,160	3,280	3,386

Source: Census of Industrial Production, Singapore

Notes: Disaggregated items represent only selected constituents. Some data were not available due to negligible amounts. Data for semiconductors in 1999 include an additional category (SSIC 31113)

Table 1. Selected economic statistics for ICT (electronic products & components) goods

Position	*Country*	*1990*	*1995*	*1999*
		Value (S $'000)	*Value (S $'000)*	*Value (S $'000)*
ASEAN				
Main	Malaysia	8,401,995,000	26,875,615,627	29,576,951,687
Top 10	Thailand	1,335,190,000	5,878,490,362	5,065,287,945
Top 10	Philippines	457,861,000	1,639,024,665	5,436,420,272
Top 50	Vietnam	N/A	214,314,516	360,651,643
Top 50	Brunei	73,701,000	171,886,693	101,707,383
Top 50	Myanmar	50,933,000	93,110,951	72,989,313
Top 50	Cambodia	N/A	73,858,178	23,756,643
Other Regional				
Top 10	Japan	8,975,380,000	20,466,178,946	16,396,762,678
Top 10	Taiwan	2,203,572,000	5,793,368,807	8,461,265,919
Top 10	Hong Kong	1,967,409,000	7,846,401,443	7,331,163,388
Top 10	Korea	1,477,690,000	6,259,598,087	5,898,454,810
Top 10	China	828,616,000	1,888,526,561	4,014,740,979
Top 50	Australia	414,686,000	735,219,728	1,078,273,275

Source: Trade Development Board

Table 2. Bilateral Trade between Singapore-ASEAN in ICT (SITC 77, 76 & 7526400) goods

Year	*GERD ($ million)*	*GERD/GDP Ratio (%)*	*No of RSEs*	*RSE/10,000 workers*	*Patents*	
					Filed	*Awarded*
1990	*571*	*0.84*	*4329*	*27.7*		
1991	*756*	*1.00*	*5239*	*33.6*		
1992	*949*	*1.17*	*6465*	*39.8*		
1993	*998*	*1.06*	*6629*	*40.5*	*142*	*52*
1994	*1120*	*1.09*	*7086*	*41.9*	*263*	*58*
1995	*1370*	*1.13*	*8340*	*47.7*	*242*	*51*
1996	*1709*	*1.37*	*10153*	*56.3*	*316*	*91*
1997	*2100*	*1.47*	*11302*	*60.2*	*490*	*132*
1998	*2500*	*1.65*	*12655*	*65.5*	*579*	*130*
1999	*2656*	*1.84*	*13817*	*69.9*	*673*	*161*

Source: National Science & Technology Board

Table 3. R&D-related statistics for Singapore, 1990-1999

Technical Appendix

This appendix will outline the two models that have been discussed in the body of the paper – the Fujita, Krugman & Venables (1999) model and the Quah (2000) model. By necessity, these are brief and possibly sketchy; the interested reader is referred back to the authors' original works.

The Fujita, Krugman & Venables (1999) model of a seamless world

The model assumes a racetrack economy where locations are spread around the circumference of a circle of radius D; thus two locations $r, s \in [0, 2\pi D]$. There are two Dixit-Stiglitz (1977) monopolistically competitive industries, with firms that are linked through the production and use of intermediate goods. Intermediate goods are assumed to be products of its own industry alone. Let the price of the industry i-specific factor at location r be $q^i(r)$. The prices charged by these firms are therefore, in a Cobb-Douglas form, for price index G and wages w, is

$$p^i(r) = [G^i(r)]^{\alpha}[w^i(r)]^{\beta}[q^i(r)]^{\kappa} \quad , \quad i = 1, 2$$

where α, β and κ represent the shares of intermediates, labour and the industry-specific factor, respectively, and $\alpha + \beta + \kappa = 1$. When factors are geographically immobile, the wage bill for industry i at location r is $w^i(r)\ \lambda^i(r)$, where λ^i is the share of density of manufacturing at location r; conversely, the value of specific factor inputs is $q^i(r)\ l^i$, where l^i is the endowment of the factor. Equilibrium implies that

$$[q^i(r)\ l^i]/\beta = [w^i(r)\ \lambda^i(r)]/\kappa$$

Choosing units of measurement such that endowment l^i is given by κ/β, for all i, the above equation reduces to

$$q(r)^i = w(r)^i\ \lambda(r)^i$$

Substituting the above into the price equation yields the prices charged by location r firms as

$$p^i(r) = [G^i(r)]^{\alpha}[w^i(r)]^{\beta+\kappa}[\lambda^i(r)]^{\kappa} \quad , \quad i = 1, 2$$

General equilibrium is determined by the price indices, wage equations and expenditure on each industry at each location. Utilising the continuous analogues[15] of the Dixit-Stiglitz model, these are:

$$\left[G^i(r)\right]^{1-\sigma} = \int_{-\pi D}^{\pi D} \left[w^i(r)\right]^{1-\alpha(\beta+\kappa)} \left[G^i(s)\right]^{-\alpha\sigma} \left[\lambda^i(s)\right]^{1-\kappa\sigma} e^{-\tau(\sigma-1)|r-s|} ds$$
$$\left\{\left[w^i(r)\right]^{\beta+\kappa} \left[G^i(r)\right]^{\alpha} \left[\lambda^i(r)\right]^{\kappa}\right\}^{\sigma} = \beta \int_{-\pi D}^{\pi D} \left[G^i(s)\right]^{\sigma-1} E^i(s) e^{-\tau(\sigma-1)|r-s|} ds$$
$$E^i(r) = \left(\frac{\beta+\kappa}{2\beta}\right) \sum_{j=1}^{2} \left[w^j(r)\lambda^j(r)\right] + \left[\frac{\alpha w^i(r)\lambda^i(r)}{\beta}\right] \quad , \quad i = 1,2$$

Here, trade costs enter the model as $T_{rs} = e^{\tau|r-s|}$, implying that $T_{max} = e^{\tau\pi}$. The model then assumes a basic ad-hoc adjustment dynamic of the form

$$\dot{\lambda}^i = \left[w^i(r) - \overline{w}(r)\lambda(r)\right] \quad , \quad i = 1,2$$

where the bar represents average wages in the two sectors at location r. Next, taking the initial conditions for a flat earth, $\lambda = ½$ and $w = 1$, yields the equilibrium conditions

$$E = 1/2\beta$$
$$G^{1-\sigma+\alpha\sigma} = \left(\frac{1}{2}\right)^{1-\kappa\sigma} \int_{-\pi D}^{\pi D} e^{-\tau(\sigma-1)s} ds$$

It is possible to express deviations from the flat earth by appending a prime on variables, such that the sinusoidal deviation in employment shares will be

$$\lambda^1(r)' = -\lambda^2(r)' = \delta_\lambda \cos(\nu r)$$

where ν is the frequency and δ_λ the amplitude of the deviation, respectively. These perturbations will influence the other endogenous variables in a likewise sinusoidal manner, yielding

$$G^1(r)' / G = -G^2(r)' / G = \delta_G \cos(\nu r)$$
$$w^1(r)' = -w^2(r)' = \delta_w \cos(\nu r)$$
$$E^1(r)' = -E^2(r)' = \delta_E \cos(\nu r)$$

Linearising the adjustment dynamic equation and substituting the above, obtain

[15] The derivations for these equations are rather involved. The interested reader is referred to Fujita, Krugman & Venables' (1999) original work, especially chapters 4-6, 14 and 16.

$$\dot{\lambda}^i(r) = \lambda w^i(r)' = \frac{\delta_w}{2}\cos(\nu r) = \frac{1}{2}\frac{\delta_w}{\delta_\lambda}\lambda^i(r)' \quad , \quad i = 1,2$$

Which gives $\delta_w/2\delta_\lambda$ as an eigenvalue. This eigenvalue can be found by totally differentiating the general equilibrium equations and solving for the change in wages induced by the change in employment,

$$\frac{\delta_w}{\delta_\lambda} = 2\left[\frac{Z(1-\rho)\left[\alpha(1+\rho) - Z(\alpha^2+\rho) - \kappa(1-Z^2)\rho\right]}{\rho(1-\alpha) - Z\alpha(1-\rho^2) - Z^2(\rho^2+\alpha^2\rho - \alpha\rho - \alpha^2)}\right]$$

where

$$Z \equiv \frac{\int_{-\pi D}^{\pi D}\cos(\nu s)e^{-\tau(\sigma-1)|s|}ds}{\int_{-\pi D}^{\pi D}e^{-\tau(\sigma-1)|s|}ds},$$
$$\sigma = 1/(1-\rho) \Rightarrow \rho = (\sigma-1)/\sigma$$

Stability of the flat earth occurs only when this eigenvalue is positive, or in other words, agglomeration only results when

$sign\,[\delta_w/\delta_\lambda] = sign\,[Z(1-\rho)[\alpha(1+\rho) - Z(\alpha^2+\rho)] - \kappa(1-Z^2)\rho] > 0$

The simulation parameters used in the paper were:

Figure 1: $\alpha = 0.4$, $\beta = 0.575$, $\sigma = 5$, $\kappa = 0$ & $\kappa = 0.025$
Figure 2: $\alpha = 0.4$, $\beta = 0.575$, $\kappa = 0.025$, $T_{max} = 4$

The Quah (2000) model for Internet cluster emergence

The model assumes three-dimensional globe where time, and not geographic distance, matters. Geography G is a unit circle in the complex plane $\{z \in \forall: |z| = 1\}$; this can be re-expressed to $\{\omega: \omega \in (-\pi, \pi]\}$, where $z(\omega) = e^{iw}$. Timeliness, T, the connection between time zones are a mapping $T: G \times G \rightarrow [0, 1]$.

Two conditions hold: first, $T(z, z) = 1 \geq T(z', z)\ \forall\ z' \in G$ and second, $T(z', z)$ depends only on $\omega(z) - \omega(z')\ \forall\ z, z' \in G$. These conditions simply imply that local production is always the most timely and timeliness varies with radial separation, not the location of production. From

$$\int_G |T(z',z)|^R dz' = \int_G |T(z,z')|^R dz' = \int_G |T(z',1)|^R dz'$$
this second condition of radial homogeneity, for any positive real number 3,

For the production side of the economy, assume that a single homogenous good Y is produced worldwide, and output at location z is given by

$$Y(z) = \left[\int_G [T(z',z)f(z')]^{\gamma} dz'\right]^{1/\gamma} \quad , \quad \gamma \in (0,1)$$

for all z in G and where the function f is the amount of factor input, which is constant through time and is given by $\int_G f(z)\, dz = 1$. This latter equation specifies f to be a probability density across geography G. Further, adjustment costs C are incurred for uprooting or planting of f, and this is represented by

$$C(\dot{f}_t(z)) = \tfrac{1}{2}\phi\, \dot{f}_t(z)^2 \quad , \quad \phi > 0$$

where the dot above the terms denotes their time derivatives. The returns to f at location z is given by

$$\begin{aligned} W_t(z) &= \int_G \frac{\partial Y(z')}{\partial f(z)} dz' \\ &= \int_G T(z,z')^{\gamma}[Y_t(z')/f_t(z)]^{1-\gamma} dz' \end{aligned}$$

Maximising the present discounted value subject to the costs of adjustment involves solving for

$$\int_{s\geq t} e^{-\rho s}[(W_s(z) - \overline{W}_s)(f_s(z) - C(\dot{f}_s(z))]ds$$

where, again, the bar represents the average returns. This optimal decision rule then satisfies

$$\dot{f}_t(z) = \phi^{-1}\int_0^{\infty} e^{-s\rho}[W_{t+s}(s) - \overline{W}_{t+s}]ds$$

By restricting the analysis to only Markov equilibria, the above equation simplifies to

$$\dot{f}_t(z) = \int_{z'\in G} M_{t,f_t}(z',z) f_t(z')dz'$$
$$\Rightarrow \dot{f}_t(z) = T_{t,f_t} f_t$$

Where M is the stochastic kernel and T, an operator with a Toeplitz property. Linearising about the uniform steady-state yields

$$\dot{f}(z) = \int_G [\theta_M(z,z')(f(z') - \overline{f}(z'))]dz' - \lambda_M(f(z) - \overline{f}(z))$$

where

$$\overline{f}(z) = (2\pi)^{-1},$$
$$\theta_M(e^{i\omega'}, e^{i\omega}) = \theta_M(e^{i(\omega'+\omega'')}, e^{i(\omega+\omega'')}) \bmod 2\pi \quad , \quad \forall M, \omega, \omega', \omega''$$

The coefficient λ_M is a real number and θ_M is the Toeplitz operator. By considering this operator, it is possible to extract its eigenfunction:

$$\begin{aligned}\int_{-\pi}^{+\pi}\theta_M(z', e^{i\omega})e^{i\omega j}d\omega &= \int_{-\pi}^{+\pi}\theta_M(1, e^{(\omega-w')i})e^{i\omega j}d\omega \\ &= e^{i\omega' j}\int_{-\pi}^{+\pi}\theta_M(1, e^{i\omega})e^{i\omega j}d\omega\end{aligned}$$

Therefore $e^{i\omega j}$ is an eigenfunction with the corresponding eigenvalue given by the Fourier coefficient

$$\int_{-\pi}^{+\pi}\theta_M(1, e^{i\omega})e^{i\omega j}dw$$

These eigenfunctions are the complete orthonormal set of complex exponentials,

$$\{(2\pi)^{-1/2}e^{i\omega j} : \omega \in (-\pi, \pi], j = -\infty, \ldots, +\infty\}$$

The real coefficient λ_M can be shown to be positive and increasing in adjustment costs coefficient ϕ. Thus as $\phi \to +\infty$, $\lambda_M \to +\infty$ and the negative real part of the spectrum for $(\theta_M - \lambda_M)$ increases.