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TECHNOLOGICAL SPECIALIZATION AND CONVERGENCE OF SMALL COUNTRIES: THE CASE OF THE LATE-INDUSTRIALIZING ASIAN NIES

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TECHNOLOGICAL SPECIALIZATION AND CONVERGENCE OF SMALL COUNTRIES: THE CASE OF THE LATE-INDUSTRIALIZING ASIAN NIES

This paper examines the changing pattern of technological specialization of the four small, newly industrializing economies (NIEs) from East Asia as they move up the economic development ladder. In addition, the paper also investigates whether there is convergence or divergence between these NIEs and two reference groups of advanced economies -- eight small, advanced European countries and the G7. We find that the East Asian NIEs had a higher degree of technological concentration than both the group of 8 advanced small European economies and the group of G7 countries, although the differences had narrowed over time. The East Asian NIEs' technological specialization pattern has also been diverging from those of the small advanced European countries, while converging among themselves (as well as towards the G7 until recently).

Key Words: Technological Specialization; Innovation; Patent Statistics; Newly Industrialized Economies

I. Introduction

The role that technology plays in the growth of modern economies has led to increasing interest in the processes of technology accumulation and specialization. Numerous attempts had been made to measure and explain these processes in the advanced countries (Pavitt 1988, Cantwell and Vertova 2002). In contrast, there has been few studies on the dynamics of technological specialization in developing countries in general and the newly industrialized economies in particular.

Studies of advanced countries' technological specialization patterns commonly use two indicators: (i) the standard deviation (or variance) and/or a Galtonian regression of the RTA (Revealed Technological Advantage), (eg Soete 1988, Pavitt 1988, Amendola et al 1998 and Laursen 2000[1]) and (ii) the Chi-square Index (Archibugi and Pianta 1992, Pianta & Meliciani 1996). Archibugi and Pianta (1994, 1998) also used the Distance Index to measure technological distance and specialization.

These studies have produced valuable information about the specialization patterns of nations. For example, one pattern that has emerged using the three measures is the higher levels of technological specialization of small countries as opposed to large countries. Some studies have also found that among these countries, those that are less developed have higher levels of specialization than those that are more advanced (see for example Pianta and Meliciani 1996; Laursen 2000).

The evidence regarding changes in specialization over time is less conclusive. A general upwards trend has been found, but there are great variations among countries and between studies and measures used (eg Archibugi and Pianta 1992, Pianta and Meliciani 1996, Amendola et al 1998, Laursen 2000).

Fewer studies have been conducted on technological specialization in developing countries. Using the Chi-square index, Mahmood and Singh (2004) found that among the four Asian NIEs (Hong Kong, Korea, Singapore, Taiwan), two countries increased their specialization over time and two decreased. No comparison of specialization levels was made with more advanced countries.

As pointed out by Dalum et al (1998), some refinement is needed to our understanding and measurement of technological specialization, in particular in distinguishing between the processes of convergence from that of concentration (see for example Dalum et al 1998). The RTA, Chi-square Index, and Distance Index are all calculated relative to some norm (usually, the world average). Thus they do not measure the level of concentration of technological activity by technology classes per se, but rather of the deviation from the world average – that is the degree of convergence to or divergence from the world norm. A separate measure of the degree of concentration (or diversification) by technological classes is thus needed to

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[1] Laursen used the Revealed Symmetric Technological Comparative Advantage (RSTA)

compare and track changes in the technological specialization patterns among countries.

This paper seeks to fill the above two gaps in the literature by benchmarking the two separate measures of technological specialization – concentration and divergence -- of the four East Asian NIEs over more than two decades (1978-2001) against a basket of eight small advanced European countries as well as against the group of G7 countries. As our data extend to 2001, our results also provide a more current analysis than is available in many studies that stopped around the early 1990s. We also tested the robustness of our findings by using more than one measure for both the concentration and divergence concept.

We have chosen to focus on the four more advanced East Asian NIEs (Taiwan, Korea, Hong Kong and Singapore), rather than a broader basket of East Asian economies, based on the fact that there is still a substantial divide in terms of technological capabilities between these four economies and the others, e.g. Malaysia, China and Thailand. As can be seen from Table 3, the other NIEs are still no where near the four in terms of patenting intensity by 2000.

We show that the East Asian NIEs are indeed more concentrated in their technological activity as compared to the advanced countries over the period 1978 to 1999. Although initially having high deviations from the world norm, they have converged strongly to the sectoral patterns exhibited by the world average, and by the large countries in particular. The small European and large advanced countries, on the other hand, are diverging away from the world average and from each other, both at the group level (ie inter-group differences are rising) and within the groups (intra-group differences are also rising).

Our findings contribute to the literature on international innovation pattern by showing not only systematic differences in technology specialization pattern between small and large advanced economies over a 24 year period, but also that distinctive patterns exist between the two groups of small economies -- the late-industrializing NIEs and the advanced small European economies. In particular, we show the usefulness of distinguishing between two conceptually different measures of technological specialization[2] - concentration and divergence – in analyzing technological specialization patterns of countries.

2. Theory development

The literature has identified two different conceptual measures of specialization: the degree of *concentration* (or its converse, diversification), and *divergence* or dissimilarities (or its converse, convergence or similarities) from some defined norm. In a study of trade patterns, Dalum et al (1998, p. 424) differentiate between the two as follows:

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[2] See also Laursen 2000

> "A specialization process refers to a process in which specialization *intra-country* becomes more dispersed (and counter-wise for de-specialisation). On the contrary, a divergence process refers to a process in which countries become more different in terms of specialization in a particular sector, *across countries* (and counter-wise for convergence).

2.1 Technological Concentration

There are two opposing factors in deciding on the portfolio of investment in technology. On the one hand, to the extent that R&D investments are risky, options theory suggests that countries should diversify their investments so as to hedge their bets. On the other hand, the theory of economies of scale suggests that a country may want to concentrate her resources into a smaller number of technological areas with the hope of achieving scale economies advantage. Scale economies may also imply a minimum absolute threshold scale, below which it is not worthwhile to engage in certain forms of R&D activities. In addition, the theory of comparative advantage suggests that different countries are likely to start off with different endowments in the resource inputs to R&D, and hence would be better off if they concentrate more resources on areas where they are better endowed to begin with. Although this argument appears more important in driving divergence among countries (see discussion in Section 2.2 below), it will also lead to more uneven distribution of resources within a given country than would otherwise be.

The economies of scale argument suggests that large countries, having a larger domestic market and greater absolute quantity of endowed resources, can afford to distribute or diversify their technological investments across many technological areas and still be able to meet or exceed the minimum threshold scale or critical mass for achieving excellence in each of these technological areas. In contrast, small countries may face greater constraints and hence must decide whether to spread the available resources more thinly over a wide variety of areas, or to focus on a few specific fields. While the former approach may have its merits from the perspective of options theory, the country may run the risk of spreading itself too thinly, and it's contribution is unlikely to be world-class in any one field. Moreover, everything else equal, larger countries are more likely to have more diversified resources, whereas small countries may have more specialized resource endowments. Taken together, the above arguments suggest that small countries are therefore more likely to concentrate their innovation efforts on a smaller number of technological fields.

Among the small countries, the late-industrializing countries are expected to face more severe resource constraints, especially in the early years of their development, than do the small countries which are already advanced to begin. Table 1 shows that the average GDP per capita for the Asian NIEs was less than half of the small advanced countries in 1980, though by 2000 they had caught up substantially, with Hong and Singapore achieving income level that even exceeded some of the advanced small advanced European and G7 countries. A picture of even more rapid catching up is found when one compares the patenting intensities of the NIEs with the small advanced European countries, as the NIEs started with an even bigger gap compared to the Europeans (see Table 1). Both Korea and Taiwan increased their income level by about 3 times over the 20 year period, but raised their patenting intensity by 146 times and 55 times respectively.

Besides sharing the same small size constraints as the group of small European countries that are already relatively advanced to begin with, the NIEs needed to grow fast, and thus were likely to pursue a higher degree of specialization to capitalize on the sectors where they had the highest comparative advantage. We would thus expect the Asian NIEs to have high levels of technological concentration – higher even than the small advanced European countries, which still have a larger pool of *cumulated* technological resources than do the NIEs. We thus have the following:

Hypothesis 1a: Small advanced economies are more concentrated in their technological activities than the large advanced countries.

Hypothesis 1b: The small East Asian NIEs are more concentrated in their technological activities than the small advanced countries.

Increasing globalization is expected to have a significant impact on how the pattern of concentration of countries' technological activities change over time. Firstly, globalization implies increasing competitive pressure from abroad, and the need for domestic firms to become not just competitive domestically, but also on a global scale. This is expected to drive increasing concentration of resources into areas where domestic firms are more globally competitive. Secondly, globalization increases international resource mobility, allowing countries which are already competitive in particular technological fields to attract even more resources from abroad to augment their domestic resource supply. Thus we would expect to see a global trend of increasing concentration of technological activities at a national level, regardless of the size of the economy or stage of development.

Mahmood (1999) argues for a U-shaped pattern of specialization change over time for NIEs. During the early phases of its industrial development, a country would have a higher level of specialization, as its economy would mainly comprise labour-intensive and natural resource-intensive activities. As this country's resources increase and it broadens its industrial activities into scale-intensive industries, its degree of specialization would be expected to decline. This de-specialization would continue until it moves into knowledge-intensive activities, at which point the need for economies of scale in R&D would lead to increasing specialization, this time in high-technology sectors (Mahmood 1999, Mahmood and Singh 2003). Thus the pattern that emerges is a U-shaped curve, with high but falling degrees of specialization in early periods and then rising levels in later periods.

Mahmood and Singh (2003) did not themselves find unambiguous evidence of this U-shaped curve. Therefore, we will confine ourselves to a more general hypothesis regarding increasing technology concentration over time over time, regardless of the stages of development:

Hypothesis 1c: The level of concentration of technological specialization for all country groups rise over time.

2.2 Technological Convergence

While the above arguments suggest that both small advanced countries and the small catching-up NIEs to have high concentration in their technological activities relative to large countries, they say nothing about whether these small countries are concentrating on similar or dissimilar technology areas as one another and as pursued by the large advanced countries. Conceptually, it is entirely possible that two countries can both have highly concentrated technology portfolios, and yet be little different from one another, because they may happen to concentrate in very similar technology areas. High concentration thus does not necessarily lead to high divergence.

The theory of comparative advantage has been used to account for why countries specialize in different things. For example, Walsh(1998) argued that small advanced countries often develop their competence and experience in niche markets that the large countries are not interested in, or are unable to compete in due to resource-specific comparative disadvantages. Small countries are therefore likely to specialize in areas that are different from the large countries and from each other, as this would give them some degree of product differentiation in the global market. Indeed, this has been found to be so in many prior studies showing small countries to have a higher level of divergence from the world norm than the large countries (eg Soete 1988, Archibugi and Pianta 1992, Archibugi and Pianta 1994, Laursen 2000).

The East Asian NIEs, at least in the earlier years of their development, would be expected to be even more different from the large advanced countries because during the early phases of their industrial development, their economies would mainly comprise labour-intensive and natural resource-intensive activities, with perhaps some scale-intensive activities, whereas the advanced countries are more specialized in knowledge-intensive activities (Mahmood 1999).

More generally, a number of prior research had identified a consistent inverse relationship between the size of the technology base and the degree of specialization in terms of divergence from the world norm (Archibugi and Pianta 1992 p. 107, Archibugi and Pianta 1994, Soete 1988[3]). Pianta & Meliciani (1996) also found that the group with the highest rates of deviation from the world average were those

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[3] These studies used indicators which measured deviation from the world norm, such as the standard deviation of the RTA and the Chi-square Index, as a measure of specialization

classified as “small, laggard countries”, which have the lowest levels of technological activities. Laursen (2000) similarly found less advanced countries to be more technologically divergent from the world norm. We therefore postulate the following::

Hypothesis 2a: The small advanced European economies have larger deviations from the world average than the large countries

Hypothesis 2b: The NIEs have larger deviations from the world average than the small advanced European countries

Just as globalization is expected to increase the propensity of countries to have more concentrated technology portfolios, we can expect globalization to increase the tendency for countries that are already relatively advanced to become technologically more differentiated over time. Being already relatively close to the technological frontiers in various technological areas, the gains from imitating or competing directly against the technological leaders are probably less than if the country is able to differentiate from others by specializing further in areas that she already has the most comparative advantage, and for which she can become a world technological leader. While this argument applies to both small and large advanced countries, smaller countries are expected to deviate more from the world norm, since the larger countries are weighted more heavily in the world norm.

In contrast to the small advanced countries, we predict that the late-industrializing economies would exhibit a different technological divergence trend over time. In particular, we note that the East Asian NIEs, in spite of their rapid technological catching up, are still somewhat behind the technological frontiers on most technology areas. Indeed, although Table 1 shows that the NIEs had by and large caught up with the advanced countries in terms of *current* patenting propensity by 2000, in terms of *cumulative* stock of patent per capita, they are still significantly behind the advanced countries on almost all technological areas, given that they started out on such a low base. As such, these late-industrializing economies do not have the option (yet) to become technological leaders themselves through differentiation. Instead, their best course of action is likely to remain one of following the leaders, i.e. specialize in the same areas of the technological leaders, with the aim to either exploit the “learning spillovers” from them, or to tap the market demand already created by these leaders through incremental or complementary innovations around the same technology areas of the leaders. Both arguments would suggest that these late-industrializing countries should converge closer to the largest technology industries in which the largest countries operate to maximize the leverage on the large technology pools (spillover learning) and large markets (gains from incremental innovation) (Laursen 2000). We thus have:

Hypothesis 3a: Deviations or divergence from the world average in terms of specialization by technology areas fall over time for the NIEs, but rise for both the small and large advanced economies

If both these arguments hold true – that small advanced countries diverge their technological activities away from those of the advanced countries over time, while the catching-up countries continue to converge towards those of the advanced countries, we would expect the small advanced countries and the catching-up countries to have *divergent* technological patterns from one another. Furthermore, we can expect the convergent and/or divergent trend to occur not only *inter*-group, but also *intra*-group as well. Hence our next hypotheses are:

Hypothesis 3b: The dissimilarity between the NIEs and small advanced countries in terms of areas of specialization rise over time, but fall between the NIEs and the large advanced countries. In contrast, the dissimilarity between small advanced countries and the large countries rise over time.

Hypothesis 3c: The intra-group differences among the NIEs fall over time. However, the intra-group differences among the small advanced European countries, and among the large countries rise over time.

2.3 Magnitude of Structural change

A change in either measures of technological specialization represent a change in the underlying structural composition of innovation activities (distribution by technology classes) from one period to another. While the above hypothesized directions of change in the technological specialization pattern of the different groups of countries over time make predictions on the *sign* of the changes (increasing concentration or diversification, and/or increasing convergence or divergence), they say nothing about the *magnitude* of the structure changes involved. Conceptually, an increasing concentration of technological portfolio over time can be accompanied by either little structural change or large structural change. This is because the increasing concentration pattern can come about through either incremental changes in the distribution across the technology classes, or through drastic transformation. For example, a technology class A that previously represents 10% of all technology classes in one period may increase to 11% in the next period, with all other classes reducing their share correspondingly; this would result in very minor structural change. However, it is conceivable that technology class A may have its share of all technology classes reduced from 10% to zero % in the next period, while another technology class, say B, that previously has zero % now having 10% share. Although there is no change in the concentration index over the two period, a significant structural change has occurred.

While the prior literature tends to emphasize path-dependency and continuity in the innovation structure of countries over time (see e.g. Nelson (ed.) 1993, and Pianta & Meliciani 1996), it does not directly address the question of whether small countries are likely to experience smaller or larger structural change than large countries, neither does it highlight differences between advanced and newly industrializing economies. There is however a considerable body of literature highlighting the rapid pace of change in the *industrial* structure of the NIEs in their industrial catch-up process (see e.g. Wong and Ng (eds) 2001). Extrapolating from this empirical evidence on the speed and magnitude of the NIE's *industrial* structural transformation in the last 25 years, which clearly exceeded what has been experienced by the advanced countries, we therefore predict that the late-industrializing NIEs would experience the largest amount of inter-period structural changes in technological specialization over the years. In contrast, we expect the large advanced countries to have experienced the smallest amount of inter-period structural change, with the small advanced countries to have intermediate experiences. Thus, our final hypothesis is:

Hypothesis 4: The Asian NIEs experience higher levels of inter-period technological structural change than the small advanced countries, which in turn have higher levels of inter-period structural change than the large countries.

3. Method

We compare the concentration and convergence of technological activity among the four Asian NIEs with eight small advanced European countries, which we shall call the S8 (Austria, Belgium, Denmark, Finland, Netherlands, Norway, Sweden and Switzerland), and with the large advanced countries of the OECD (i.e. the G7 comprising US, Japan, Germany, France, Italy and Canada).

The eight small advanced countries were chosen on the basis of per capita national income. Table 2 shows that among the small countries in Europe, these eight, together with Ireland, had the highest GNP per capita in 1999. Moreover, a clear gap is seen between the last of these eight economies (Sweden) and the next highest among the other European countries (Spain) in terms of per capita income level. We excluded Ireland as its per capita income level was lower than the other eight at the beginning of our study period (1978), and moreover, Ireland's patenting intensity was much lower than the other eight at the beginning of our study period. Anyway, we have conducted sensitivity analysis and found that the inclusion of Ireland results in no change to our findings.

3.1 Data Sources

Following the tradition of technological specialization studies, we used US patent data. Although not perfect, patent data are the best available indicators for such an analysis, given the detailed data made available for many countries over a long time period. The US patent database allows a high degree of international comparability, and given the US' position as the world's largest technology market, it is reasonable to assume that any technology aimed at the international market will be registered there (Archibugi and Pianta 1994).

One problem with using US patent data is the higher propensity to register a patent in one's own country rather than overseas; as such, results for the US are not wholly comparable with those of other countries. However, when comparing degrees (rather than fields) of specialization, this problem is somewhat muted. Another limitation is that patenting at home tends to be broader-based (i.e. less specialized) than overseas, so that other things being equal, concentration levels in the US will be understated (Pianta and Meliciani 1996).

It is common practice in technological specialization studies to use the first country listed in the patent (Mahmood and Singh 2003). However, in order to more fully capture the scope of countries' technological activities, we have taken into account the countries of all inventors referred to in each patent. This is similar to Laursen's (2000) approach, although in our study we counted a full patent for every country that contributed to each individual patent, rather than 1/m patents to each m countries referred to in the patent. Similarly, one patent was attributed to each sector referred to in the patent. Our data was categorized according to the 21 subsections of the sixth edition of the IPC (see Annex Table A1). Previous studies have generally used a finer level of aggregation, basing their analysis on their analysis on 30 or 40 classifications (eg Archibugi and Pianta 1992, Pianta and Meliciani 1996, Amendola et al 1998, Mahmood and Singh 2003). While classification of patent data according to the US patent classification system has also commonly been used, we utilized the International Patent Classification (IPC) system to be more compatible with several prior studies

As with other studies, the patent data has been aggregated across several years in order to reduce year-to-year fluctuations. In particular, we divided the 24 year timeframe (1978-2001) into four equal six-year time periods for each measure: 1978-1983, 1984-1989,1990-1995 and 1996-01.

3.2 Indicators

Since concentration and convergence represent two conceptually different ways to interpret technological specialization, we need to measure them using different constructs. To increase robustness, we use multiple measures, or indicators, for each of these two specialization constructs. In addition, we introduce an indicator to measure the structural difference between two distributions of patents by patent classes. All the indicators used are well established measures from the prior literature on measuring specialization, although some of them have been less used in the context of technological specialization.

Indicators for Technological Concentration

Gini coefficient

The Gini coefficient measures the degree of inequality in a distribution, ranging from 0 (no inequality) to 1 (complete inequality). Although usually used to measure income inequality, it has also been used to measure technological specialization. Mancusi (2001) used the Gini coefficient to measure geographical concentration of the production of innovation for a number of technology fields.

Herfindahl Index

Although typically used as a measure of market concentration, the Herfindahl Index has also been used to measure countries' specialization in manufacturing (eg Weinhold and Rauch 1997). Here we have modified it to measure technological specialization so that the formula becomes

$$H = \sum_i s_i^2$$

where s_i is the country's share of patents in the ith patent class

Specialization Index

The specialization index is similar to the Herfindahl index. Also independent of the world total, it has been used by UNIDO to measure the degree of specialization of countries' manufacturing activities (UNIDO 1997). For our purposes the index is:

$$h = 100 * \left(1 + \frac{\sum_i s_i * \ln s_i}{h_{\max}} \right)$$

s_i = the share of the ith branch in total patents in the year and $h_{\max}$ is the natural logarithm of the number of patent classes.

The index ranges from 0 (when all patent classes have the same share) to 100 (all patents are in one class)

Indicators for Technological Convergence

Standard Deviation of Revealed Technological Advantage (RTA)

The formula for the RTA is:

$$RTA_{ij} = \frac{n_{ij} / \sum_i n_{ij}}{\sum_j n_{ij} / \sum_i \sum_j n_{ij}}$$

Where n_{ij} is the number of patents of country i in technological class j registered with the USPTO. Values above one show a relative specialization in that patent class, and vice versa for values below one.

The indicator we use is then the standard deviation of the RTA index, ie:

$$StdDevRTA = \sqrt{\frac{n\sum_i x_i^2 - \left(\sum x_i\right)^2}{n^2}}$$

where x_i is the RTA for each sector within each country.

Chi-squared index

The chi-squared statistic is calculated by comparing the "percentage distribution across sectors of the science or technology activities for a given country and the percentage distribution of the world total" (Archibugi & Pianta (1992 p. 104). Like the RTA, it shows the extent to which countries concentrate their patents across sectors relative to the world average (Pianta and Meliciani 1996).

The formula for the chi-squared statistic is:

where: *i* is the country under consideration
j is the sectors of the distribution

$$\chi_i^2 = \sum_j \frac{(p_{ij} - p_{wj})^2}{p_{wj}}$$

p_{ij} is the percentage of the variable considered held by country i in class *j*
p_{wj} is the percentage of the variable considered for the world total in class *j*

If the country's distribution of patents is the same as the world total, the index takes a value of 0, and grows rapidly as the two distributions diverge.

The chi-squared index has several limitations. One is its sensitivity to extreme values. Another is that since it is based on countries' deviations from the world average, the larger a country's US patenting, the larger its contribution to the world average and hence the lower its value (Pianta and Meliciani 1996).

Indicators for Structural Difference

Distance index

The distance index is an application of the chi-squared index, measuring the distance between pairs of countries in terms of their US patenting activities in different sectors (Archibugi & Pianta 1994). The formula for the distance index is:

$$D_{ab} = \frac{\left[\sum_{i=1}^{n} (p_{ia} - p_{ib})^2 / p_{iw}\right]}{D_{\max}} * 1000$$

where: D_{ab} is the distance index between country a and country b
p_{ia} is the percentage of patents in country a in sector i

p_{ib} is the percentage of patents in country b in sector i
p_{iw} is the percentage of patents of the world total in sector i
n is equal to the number of patent classes
D_{max} is the maximum value of the distance for a given world distribution in n classes

Values for the indicator range from 0, for two countries with exactly the same percentage distribution of patents across all the patent classes, to 1000.

One advantage of the distance index is that it compares patents within each patent class, which allows for the fact that the propensity to patent varies across sectors.

4. Results

Hypothesis 1

A summary of results is provided in Table 4. All the indicators for concentration (the Gini Coefficient, the Herfindahl Index and the Specialization Index) show the NIEs as having the highest specialization levels in all four time periods (Figures 1-3). Hypothesis 1b is thus supported.

However, all three indicators show the group of small advanced European countries (S8) as having very similar levels of concentration to the large countries – in fact, the G7 are marginally less concentrated than the S8. Hypothesis 1a is thus not supported.

The Gini Coefficient, Herfindahl Index and Speciaization Index all show increasing levels of concentration for the three country groups over time. Hypothesis 1c is supported.

Hypothesis 2

In the earlier periods (1978-83 and 1984-89), the NIEs had the highest levels of Chi-square Index and standard deviations of the RTA, followed by the S8 and then the G7. However in later periods (1990-95 for the standard deviation of the RTA and 1996-01 for the Chi-square Index), the NIEs converged so strongly that they had lower deviations from the world norm than did the S8. Thus Hypothesis 2b is only supported in the earlier periods. Hypothesis 2a is supported as S8 stays above G7 throughout all four periods on both the RTA and Chi-square measures.

Hypothesis 3

In support of Hypothesis 3a, the Chi-square Index and standard deviation of the RTA show the NIEs to be reducing their deviations from the world average, while the S8 and G7 increasingly diverged from the world norm over time. The latter result is stronger for the S8 than the G7 (Figures 4-5).

The Distance Index provides a measure of the magnitude of the structural change taking place in the countries' patenting activities over different time periods. Over time the NIEs' technology specialization patterns grew more similar to the large countries, although there was some reversal of this in the last period (Figure 6a). However, they have increasingly specialized in areas distinct from the S8, as reflected in the increasing value of the S8-NIE distance index from 1978-83 to 1995-99. The technological distance between the S8 and the G7 also rises over time. Hypothesis 3b is generally supported.

Hypothesis 3c is also supported, with the intra-group differences among the NIEs falling steadily from 1987-83 to 1996-01, while the intra-group differences for the S8 and the G7 rose over the same period (Figure 6b).

Hypothesis 4

Hypothesis 4 is also supported. As can be seen from Figure 6c, as measured by the Distance Index, the average inter-period (1st to 4th period) difference for the NIEs is substantially larger than that for the S8, which in turn is higher than that for the G7.

5. Discussion and Conclusion

Our results provide the first empirical evidence on the pattern of technological specialization of the East Asian NIEs, how they have changed over time, and whether they have converged or diverged from the small advanced European countries as well as the G7 group of large advanced countries. The findings seem to largely support the hypothesized patterns and trends. In particular, they show that the NIEs, in the process of catching up, had increased the degree of concentration of their patenting in terms of technology classes, which were consistently higher than those of the S8 and the G7 countries. This finding is robust to the choice of measures of concentration used (Gini Coefficient, Herfindahl Index and Specialization Index).

Our results also show that the NIEs were converging towards the pattern of specialization by technology classes of the large advanced countries (G7) over time, while diverging from the pattern of the S8. Thus, the "catching-up" of the NIEs was primarily with reference to the G7. In contrast, their technology specialization pattern was becoming more dissimilar from the S8, partly because the S8 themselves were becoming increasingly dissimilar from the G7. This inter-group finding is mirrored by the intra-group finding that the NIEs were becoming more similar to one another in their technological specialization while the S8 countries (as well as the G7) were becoming less similar.

The results thus strongly suggest quite different competitive dynamics going on between the NIEs and the S8. On the one hand, in trying to “catch up”, the NIEs appear to be targeting the large advanced countries as their reference models, but with greater degree of concentration to enhance their competitiveness in view of their small size. Intra-country differences among the NIEs are reduced over time, since they appear to target similar high technology areas, particularly electronics and IT, that the G7 were strong in. The S8 economies, in contrast, were already relatively advanced since the late 1970s, and thus were seeking to differentiate themselves, both from the large countries as well as from one another, in order to stay competitive. The large countries in the G7 group are similarly diverging from one another’s technology specialization pattern, but at a lower pace from that of the S8, possibly because of the greater degree of inertia that large countries may face.

Our results also appear to confirm the usefulness of the conceptual distinction between specialization in the sense of concentration of technological activities by technology classes as opposed to divergence or dissimilarities of technological activities from some reference norm. That these are two distinct phenomena captured by different indicators is reflected in the correlation coefficients of the indicators (see Table 5). The Gini Coefficient, Specialization Index, and Herfindahl Index, which measure the concentration are strongly related, having Pearson correlation coefficients of about 0.9. Similarly, the standard deviation of RTA and the Chi-square Index, which both measure convergence, are also highly correlated (Pearson correlation coefficient = 0.76). However, the Chi-square measure has much weaker correlation with the three measures of concentration, while the correlation of RTA with the three concentration measures were statistically insignificant.

The differences in the relationship between concentration and convergence vs. the size of economy can also be seen from Annex C, which shows the results of regressing the various concentration and convergence indices on economy size for the 19 economies covered in our study. As can be seen, whether measured in terms of GDP or cumulative number of patents, the convergence measures exhibit significant negative correlation with economic size, whereas the concentration measures show weak to no correlation.

One important outcome of measuring technological specialization in terms of these two dimensions is our finding that the small advanced European countries appear to have *lower* concentration of technological activities than the large countries, even though they are found to have *higher* divergence or dissimilarities from the world norm. While much of the existing literature has emphasized the latter finding (see e.g. Archibugi & Pianta 1992, Pianta & Meliciani 1996) as evidence of higher technological specialization of small countries, the former dimension has not been earlier explored, and our finding appears to be unexpected. Further research is needed to explain why the small advanced European countries are actually more diversified by technology classes than the large countries, even as they become more dissimilar from the large advanced countries. One possible explanation is that these economies are trying to do two things simultaneously: concentrating more of their R&D investments in selected niche natural resource-based technology areas where they had historically built up competitive strengths (e.g. wood-based technologies (Sweden, Norway and Finland), and shipping (Norway, Denmark and the Netherlands)), while at the same time diversifying into non-natural resource-based technological areas like electronics and telecommunications.

To test the robustness of our findings, we have also tried a number of variations in terms of the choice of countries to be included in the reference set of small, advanced countries. We added Ireland, Australia and New Zealand into the set and obtained similar results. We also tried removing Hong Kong from the group of NIEs, on the ground that Hong Kong has pursued a less technology development-focused economic development strategy than the other three NIEs (Wong and Ng (eds.) 2001). As can be seen from Annex B, the results remain largely similar, except that the divergence measures show an increase from the first to second period, before continuing their decrease in the third and fourth period, rather than a continuous decrease throughout the four periods. This suggests that the three NIEs' went through a much more concentrated shift towards IT than was pursued by the advanced G7 countries during the period of 1984-89. Lastly, we tested the sensitivity of our findings to the use of a more disaggregated classification of technology areas for a subset of the indicators; while the absolute values are different, the qualitative findings remain unchanged.

In conclusion, our findings contribute to the literature on national innovation systems by highlighting the different competitive dynamics that drive technological specialization of small versus large countries in general, and among small, late-industrializing economies versus small, advanced economies in particular. Our findings also call for the need to distinguish the two dimensions of technological specialization – concentration vs. convergence -- to achieve greater insights on the dynamics of international technological competition.

Table 1 GDP per capita and patents per capita for S8, Asian NIEs and G7, 1980 and 2000

		Real GDP per capita			Patents per capita			Population
		($constant, 1996)		Growth rate (%)	(patents per million)		Growth rate (%)	(millions)
		1980	2000	1980-2000	1981	2000	1981-2000	2000
S8	Austria	15,706.0	23,681.3	2.1	37.5	66.2	3.0	8.1
	Belgium	16,302.8	23,784.3	1.9	28.5	73.7	5.1	10.3
	Denmark	18,281.7	26,627.2	1.9	26.9	95.4	6.9	5.3
	Finland	15,484.2	23,798.5	2.2	32.3	125.4	7.4	5.2
	Netherlands	16,163.6	24,313.2	2.1	46.8	88.6	3.4	15.9
	Norway	16,771.6	27,044.0	2.4	23.9	59.2	4.9	4.5
	Sweden	17,179.4	23,661.8	1.6	103.7	195.9	3.4	8.9
	Switzerland	22,319.7	26,421.6	0.9	199.3	202.9	0.1	7.2
NIE	Hong Kong	12,516.1	26,703.4	3.9	13.1	80.6	10.0	6.8
	Korea	4,829.5	15,881.3	6.1	0.5	73.4	30.0	47.3
	Singapore	11,460.3	24938.8[a]	4.0	1.6	60.2	21.0	4.0
	Taiwan	5,849.9	17056.1[b]	5.5	4.8	266.6[c]	23.5	21.8
G7	Canada	19,022.3	26,922.2	1.8	51.5	127.6	4.9	30.8
	France	16,201.1	22,371.4	1.6	41.1	69.1	2.8	60.4
	Germany	15,840.7	22,861.1	1.9	82.3	131.7	2.5	82.2
	Italy	15,161.4	21,794.2	1.8	16.5	34.1	3.9	57.7
	Japan	15,631.2	24,671.7	2.3	74.4	259.4	6.8	126.9
	UK	14,340.1	22,188.2	2.2	46.2	68.4	2.1	59.8
	US	21,336.6	33,308.4	2.3	188.0	352.2	3.4	275.4

[a] Figure for 1996

[b] Figure for 1998

[c] Calculated using 1998's population figures

Note: Components of Real GDP per capita are obtained by extrapolating the 1996 values in international dollars from the Geary aggregation using national growth rates. It is a fixed base index where the reference year is 1996.

Source: Heston, A., Summers, R. and Aten, B. (2002). *Penn World Table Version 6.1*, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002. Downloaded from http://pwt.econ.upenn.edu/

United States Patent and Tradement Office. (2002). *Patent counts by country/state and year: All patents, all types, January 1, 1977 - December 31, 2001*. A Technology Assessment and Forecast Report, February 2002, downloaded from http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm

Table 2 Real GDP per capita 2000 for small European countries

	$ constant
Norway	27,043.97
Denmark	26,627.16
Switzerland	26,421.59
Ireland	26,378.97
Netherlands	24,313.17
Finland	23,798.48
Belgium	23,784.25
Austria	23,681.31
Sweden	23,661.82
Spain	18,054.65
Portugal	15,955.13
Greece	14,624.61
Czech Republic	13,673.13
Hungary	10,443.70
Poland	9,228.51
Turkey	6,837.72
Slovak Republic	4,434.91

Source: Heston, A., Summers, R. and Aten, B. (2002). *Penn World Table Version 6.1*, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002. Downloaded from http://pwt.econ.upenn.edu/

Table 3 Patents per capita (no. of patents per million) 1981-2000

	1981	1990	2000
Hong Kong	13.09	26.47	80.62
Korea	0.46	6.76	73.44
Singapore	1.58	5.25	60.23
Taiwan	4.84	42.56	266.61 [a]
Chile	0.18	0.15	1.05
China	0.00	0.04	0.13
India	0.01	0.03	0.13
Mexico	0.67	0.42	1.03
Malaysia	0.07	0.33	2.02
Thailand	0.04	0.05	0.49

[a] Calculated using 1998's population figures

Source: Heston, A., Summers, R. and Aten, B. (2002). *Penn World Table Version 6.1*, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002. Downloaded from http://pwt.econ.upenn.edu/
United States Patent and Tradement Office. (2002). *Patent counts by country/state and year: All patents, all types, January 1, 1977 - December 31, 2001*. A Technology Assessment and Forecast Report, , February 2002, downloaded from http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm

Table 4 Summary of results

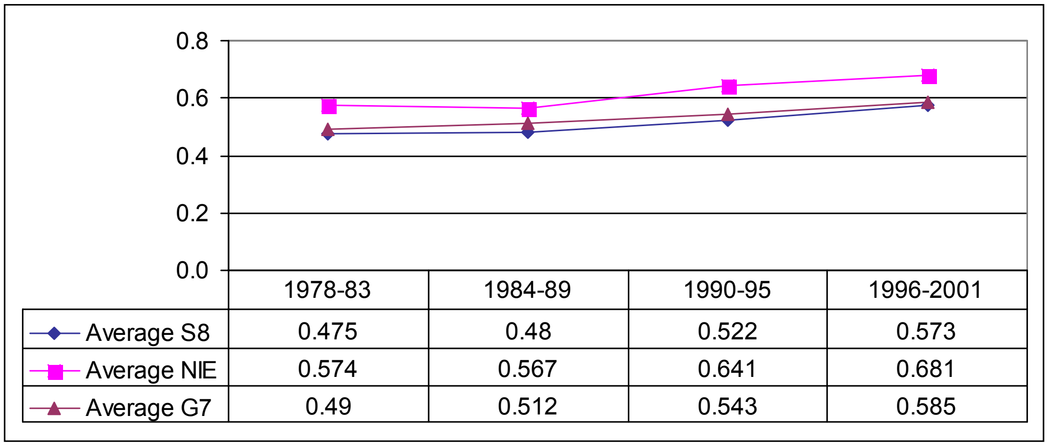
Hypothesis no.	Statement of hypothesis	Result
Hypotheses regarding concentration		
1a	Small advanced countries are more concentrated than the large advanced countries	Not supported
1b	NIEs are more concentrated than small advanced countries	Supported
1c	Concentration for all country groups rises over time	Supported
Hypothesis regarding convergence		
2a	Small advanced countries have larger deviations from world average than large countries	Supported
2b	NIEs have larger deviations from world average than the small advanced countries	Supported for earlier periods
Hypotheses regarding changes in convergence over time		
3a	Deviation from the world average falls over time for NIEs	Supported
	Deviation from the world average rises over time for small and large advanced countries	
3b	Dissimilarity between NIEs and small advanced countries rises over time	Supported
	Dissimilarity between small advanced countries and large countries rises over time	Supported
	Dissimilarity between NIEs and large countries falls over time	Supported for earlier periods
3c	Intra-group differences among the NIEs fall over time	Supported
	Intra-group differences among small advanced countries and large countries rises over time	
Hypotheses regarding magnitude of structural change		
4	NIEs have higher levels of structural change over time than the small advanced countries	Supported
	Small advanced countries have higher levels of structural change than the large countries	

Table 5 Correlation of specialization indicators

	Chi-Square Index	Standard Deviation of RTA	Gini Coefficient	Specialization Index	Herfindahl Index
Chi-Square Index	1.000	.739**	.241*	.267*	.199
Standard Deviation of RTA		1.000	.036	.042	-.021
Gini Coefficient			1.000	.972**	.903**
Specialization Index				1.000	.969**
Herfindahl Index					1.000

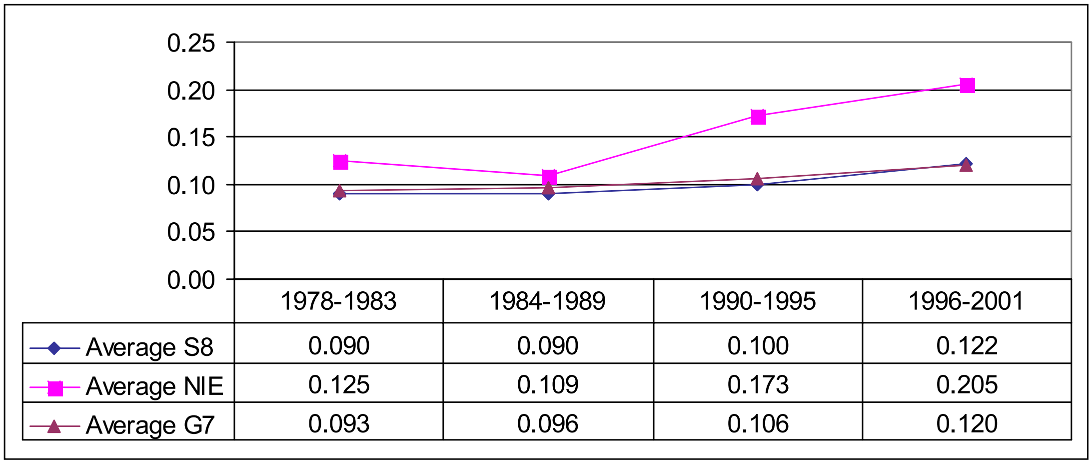
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Figure 1 Gini Coefficient



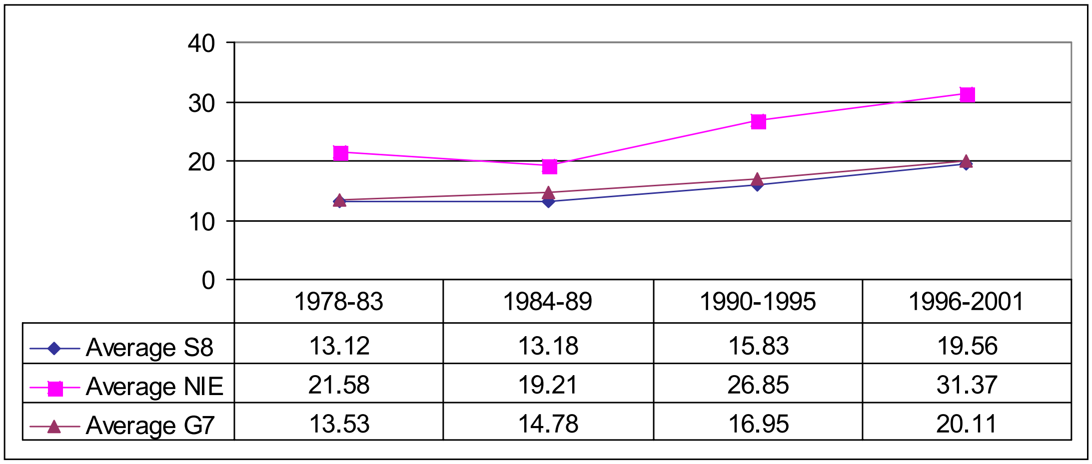
	1978-83	1984-89	1990-95	1996-2001
◆ Average S8	0.475	0.48	0.522	0.573
■ Average NIE	0.574	0.567	0.641	0.681
▲ Average G7	0.49	0.512	0.543	0.585

Figure 2 Herfindahl Index



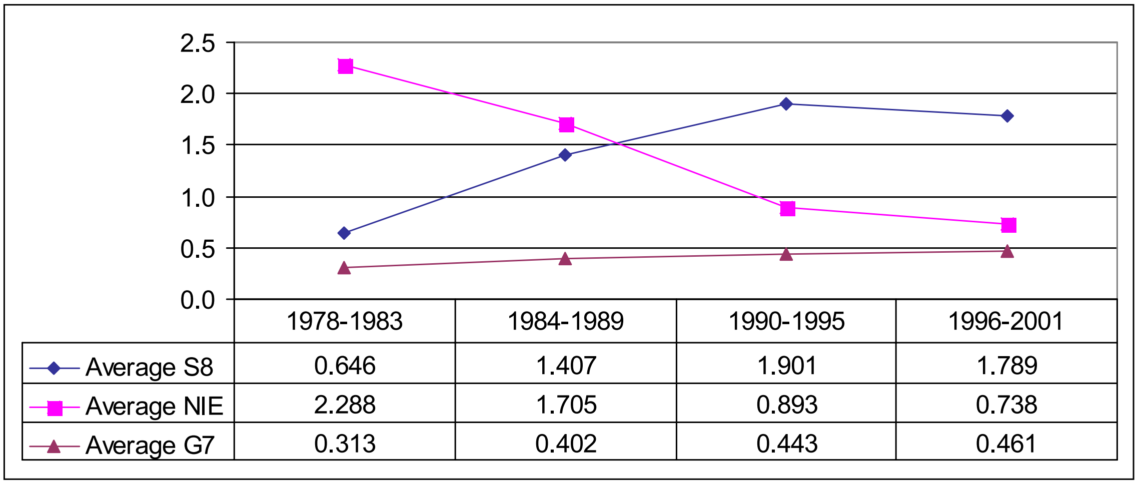
	1978-1983	1984-1989	1990-1995	1996-2001
◆ Average S8	0.090	0.090	0.100	0.122
■ Average NIE	0.125	0.109	0.173	0.205
▲ Average G7	0.093	0.096	0.106	0.120

Figure 3 Specialization Index



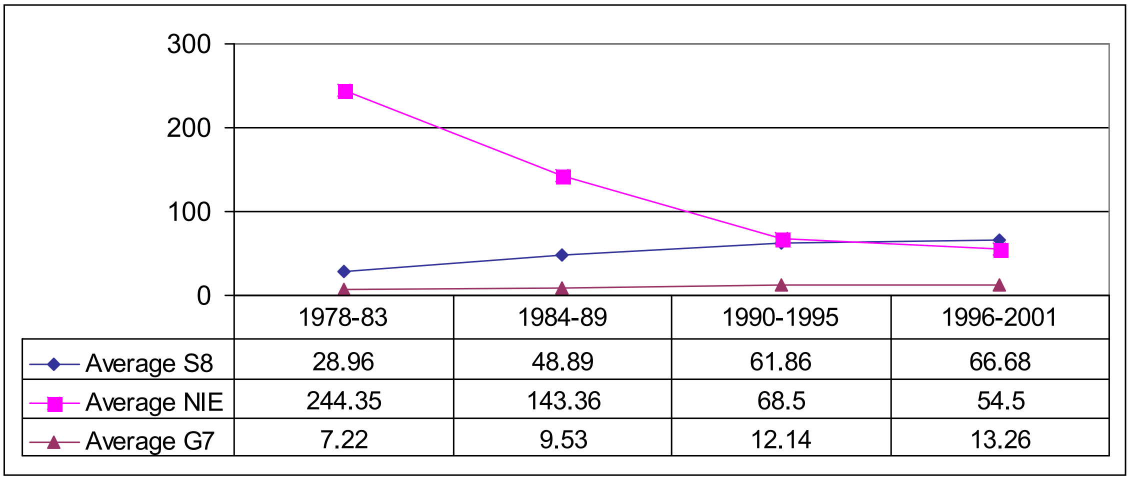
	1978-83	1984-89	1990-1995	1996-2001
◆ Average S8	13.12	13.18	15.83	19.56
■ Average NIE	21.58	19.21	26.85	31.37
▲ Average G7	13.53	14.78	16.95	20.11

Figure 4 Standard Deviation of RTA



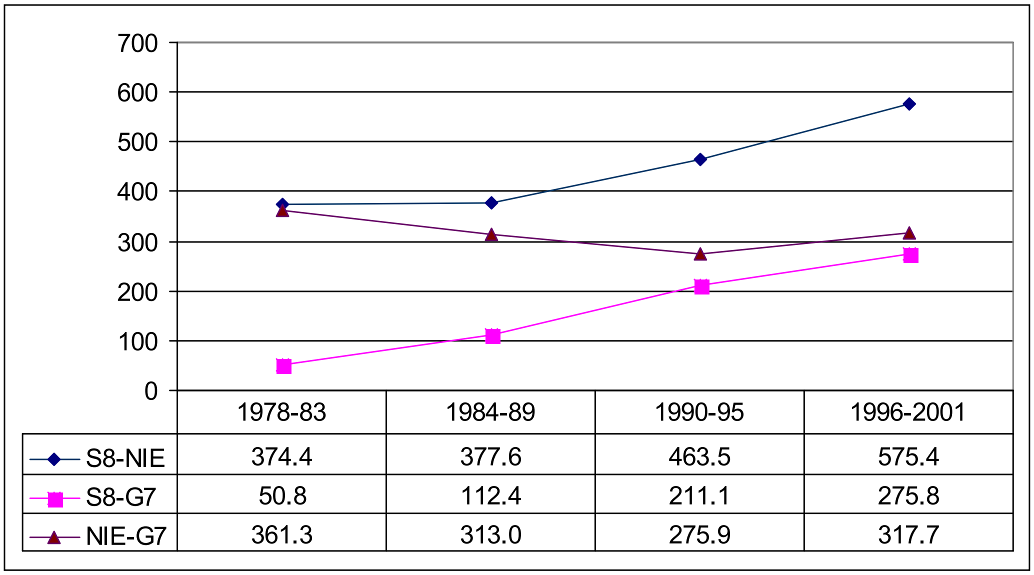
	1978-1983	1984-1989	1990-1995	1996-2001
Average S8	0.646	1.407	1.901	1.789
Average NIE	2.288	1.705	0.893	0.738
Average G7	0.313	0.402	0.443	0.461

Figure 5 Chi-square Index



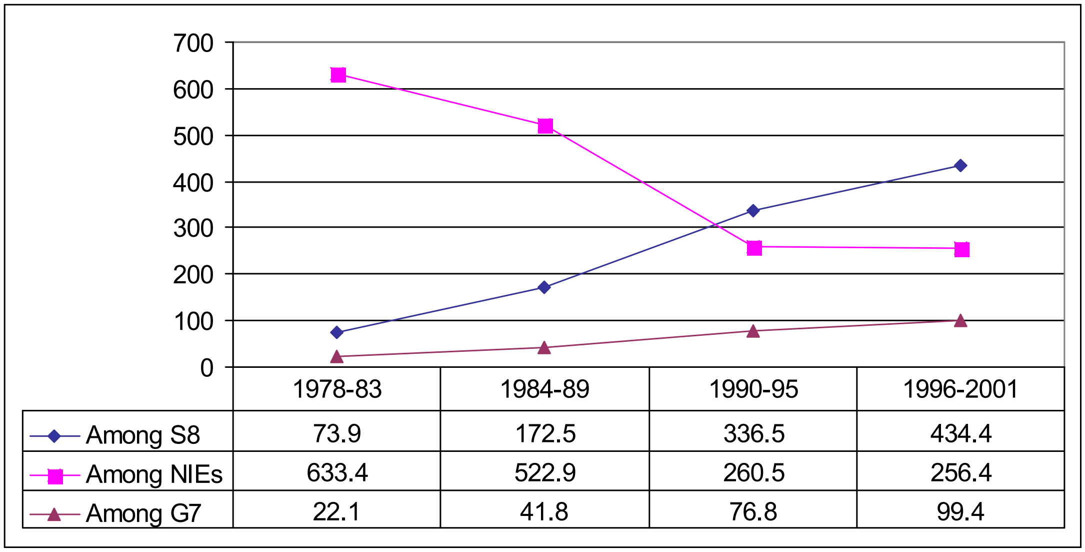
	1978-83	1984-89	1990-1995	1996-2001
Average S8	28.96	48.89	61.86	66.68
Average NIE	244.35	143.36	68.5	54.5
Average G7	7.22	9.53	12.14	13.26

Figure 6a Inter-group Distance Index



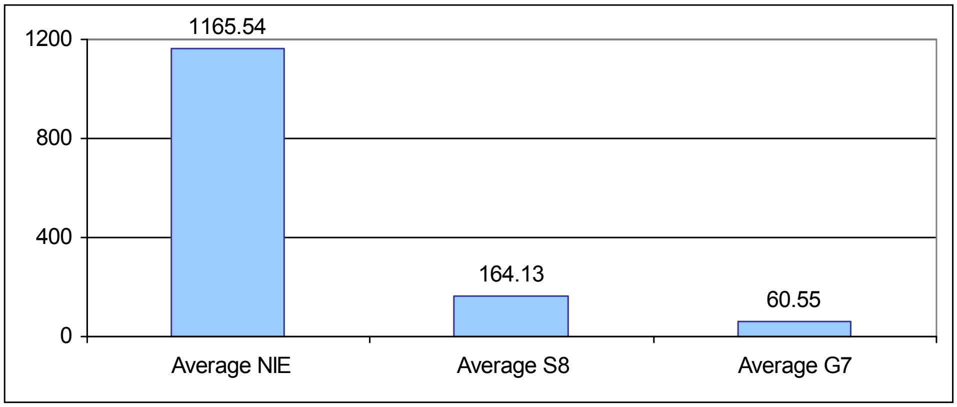
	1978-83	1984-89	1990-95	1996-2001
S8-NIE	374.4	377.6	463.5	575.4
S8-G7	50.8	112.4	211.1	275.8
NIE-G7	361.3	313.0	275.9	317.7

Figure 6b Intra-group Distance Index



	1978-83	1984-89	1990-95	1996-2001
◆ Among S8	73.9	172.5	336.5	434.4
■ Among NIEs	633.4	522.9	260.5	256.4
▲ Among G7	22.1	41.8	76.8	99.4

Figure 6c Intra-Country Distance Index for 1978/83-1996/2001



Annex A

Table A1 Classifications used for patent data

	IPC version 6 subsections
A0	Agriculture
A2	Foodstuffs; tobacco
A4	Personal or domestic articles
A6	Health; amusement
B0	Separating; mixing
B2+B3	Shaping
B4	Printing
B6	Transporting
C0+C1	Chemistry
C2+C3	Metallurgy
D0	Textile or flexible materials not otherwise provided for
D2	Paper
E0	Building
E2	Earth or rock drilling; mining
F0	Engines or pumps
F1	Engineering in general
F2	Lighting; heating
F4	Weapons; blasting
G0+G1	Instruments
G2	Nucleonics
H0	Electricity (section H)

Source: WIPO website, http://www.wipo.int/classifications/fulltext/new_ipc/index.htm

Annex B

Table B1 Indicators for NIEs including and excluding Hong Kong

	Time Period			
	1978-83	1984-89	1990-95	1996-2001
Gini Coefficient (incl HK)	0.574	0.567	0.641	0.681
Gini Coefficient (excl HK)	0.537	0.548	0.648	0.711
Herfindahl Index (inc HK)	0.125	0.109	0.173	0.205
Herfindahl Index (excl HK)	0.107	0.102	0.188	0.234
Specialization Index (incl HK)	21.58	19.21	26.85	31.37
Specialization Index (excl HK)	18.87	18.00	28.28	35.00
Standard Deviation of RTA (incl HK)	2.288	1.705	0.893	0.738
Standard Deviation of RTA (excl HK)	1.851	1.898	0.801	0.606
Chi-square Index (incl HK)	244.35	143.36	68.50	54.50
Chi-square Index (excl HK)	124.52	166.35	64.83	49.97
Inter-group Distance Index: S8-NIE (incl HK)	374.4	377.6	463.5	575.4
Inter-group Distance Index: S8-NIE (excl HK)	504.52	422.31	473.59	597.25
Inter-group Distance Index: NIE-G7(incl HK)	361.3	313.0	275.9	317.7
Inter-group Distance Index: NIE-G7(excl HK)	437.34	359.62	273.88	319.72
Intra-group Distance Index (incl HK)	633.4	522.9	260.5	256.4
Intra-group Distance Index (excl HK)	725.95	671.09	275.14	140.47
	1978/83-1996/2001			
Intra-Country Distance Index (incl HK)	1165.54			
Intra-Country Distance Index (excl HK)	710.00			

Table B2 Indicators for NIEs including and excluding Ireland

	Time Period			
	1978-83	1984-89	1990-95	1996-2001
Gini Coefficient (excl IE)	0.574	0.567	0.641	0.681
Gini Coefficient (incl IE)	0.543	0.560	0.636	0.677
Herfindahl Index (excl IE)	0.125	0.109	0.173	0.205
Herfindahl Index (incl IE)	0.115	0.106	0.163	0.193
Specialization Index (excl IE)	21.58	19.21	26.85	31.37
Specialization Index (incl IE)	19.48	18.60	25.93	30.44
Standard Deviation of RTA (excl IE)	2.288	1.705	0.893	0.738
Standard Deviation of RTA (incl IE)	1.979	1.486	0.830	0.688
Chi-square Index (excl IE)	244.35	143.36	68.50	54.50
Chi-square Index (incl IE)	199.74	117.18	57.51	45.99
Inter-group Distance Index: S8-NIE (excl IE)	374.4	377.6	463.5	575.4
Inter-group Distance Index: S8-NIE (incl IE)	312.0	325.0	422.9	518.8
Inter-group Distance Index: NIE-G7(excl IE)	361.3	313.0	275.9	317.7
Inter-group Distance Index: NIE-G7(incl IE)	297.4	259.3	238.8	273.2
Intra-group Distance Index (excl IE)	633.4	522.9	260.5	256.4
Intra-group Distance Index (incl IE)	523.8	443.1	226.7	257.9
	1978/83-1996/2001			
Intra-Country Distance Index (excl IE)	1165.54			
Intra-Country Distance Index (incl IE)	980.65			

Annex C

Table C1 Regression results of specialization indicators against cumulative patents

Equation used:
specialization indicator for period $i = \alpha + \beta \ln$ (cumulative patents at beginning of period i)

i	α	β	Adjusted R-squared
CONVERGENCE INDICATORS			
Chi-squared Index			
1978-83	255.84**	-31.84*	0.266
1984-89	257.80**	-26.33**	0.368
1990-95	154.66**	-12.58*	0.208
1996-2001	169.84**	-13.32**	0.320
Standard deviation of RTA			
1978-83	2.657**	-0.300**	0.571
1984-89	3.438**	-0.302*	0.220
1990-95	2.744	-0.183	0.004
1996-2001	3.104*	-0.215	0.067
CONCENTRATION INDICATORS			
Gini coefficient			
1978-83	0.566**	-0.011	0.045
1984-89	0.534**	-0.003	-0.045
1990-95	0.659**	-0.012	0.065
1996-2001	0.677**	-0.008	-0.006
Herfindahl Index			
1978-83	0.123**	-0.004	0.075
1984-89	0.099**	0.000	-0.057
1990-95	0.203**	-0.010*	0.165
1996-2001	0.230**	-0.010	0.081
Specialization Index			
1978-83	21.757**	-1.127†	0.152
1984-89	17.740**	-0.350	-0.017
1990-95	30.274**	-1.343†	0.137
1996-2001	33.165**	-1.159	0.041

Notes:
For the period 1978-1983, the number of patents at the end of 1978 has been used as a proxy for the cumulative number of patents at the beginning of the period
N=19. Countries included in sample: Austria, Belgium, Denmark, Finland, Netherlands, Norway, Sweden, Switzerland, Hong Kong, Korea, Singapore, Taiwan, Canada, France, Germany, Italy, Japan, UK and US
**Significant at 0.01 level
***** Significant at 0.05 level
† Significant at 0.1 level

Data source: PatentView: U.S. patent information on CD-ROM; *Historic Patents By Country, State, and Year - Utility Patents*, USPTO Web Site, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm

Table C2 Regression results of specialization indicators against GDP

Equation used:
specialization indicator for period i = $\alpha + \beta \ln$ (GDP for first year of period i)

i	α	β	Adjusted R-squared
CONVERGENCE INDICATORS			
Chi-squared Index			
1978-83	679.42**	-52.58*	0.254
1984-89	531.96**	-39.97*	0.281
1990-95	327.39**	-22.12*	0.252
1996-2001	341.61**	-22.65**	0.395
Standard deviation of RTA			
1978-83	6.434**	-0.477**	0.503
1984-89	7.771**	-0.558*	0.269
1990-95	6.847†	-0.446	0.082
1996-2001	7.314*	-0.475*	0.196
CONCENTRATION INDICATORS			
Gini coefficient			
1978-83	0.648**	-0.013	-0.010
1984-89	0.479**	0.003	-0.055
1990-95	0.637**	-0.006	-0.045
1996-2001	0.638**	-0.003	-0.056
Herfindahl Index			
1978-83	0.164**	-0.006	0.030
1984-89	0.079†	0.001	-0.048
1990-95	0.212†	-0.007	-0.010
1996-2001	0.239†	-0.008	-0.023
Specialization Index			
1978-83	32.56*	-1.501	0.073
1984-89	15.84†	-0.067	-0.058
1990-95	30.80†	-0.959	-0.021
1996-2001	31.43	-0.700	-0.044

Notes:
N=19. Countries included in sample: Austria, Belgium, Denmark, Finland, Netherlands, Norway, Sweden, Switzerland, Hong Kong, Korea, Singapore, Taiwan, Canada, France, Germany, Italy, Japan, UK and US
**Significant at 0.01 level
* Significant at 0.05 level
† Significant at 0.1 level

Data source: PatentView: U.S. patent information on CD-ROM; *Global Market Information Database,* Euromonitor

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