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Are technological specialization patterns random or cumulative in East Asia? An analysis of patent statistics

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1. Introduction

As industrial technologies grow increasingly complex, regardless of whether they are tacit or codified and explicit, the necessary knowledge and skills have become largely specific to particular categories of industry, products and processes. As a result, the technologies accumulated through each of the activities, can be thought of as being differentiated by the specialized patterns reflecting the content of each learning process (Bell and Pavitt, 1997). That is to say, as a result of the specific directions in which technological changes are lead by previous learning, differences among countries in the resources devoted to such deliberate learning or technological accumulation have led to international differences in technological specialization patterns. Previously established technological specialization patterns are therefore mutually stable, and there is a high likelihood that the sectors in which each country is technologically strongest only change gradually (Pavitt, 1988).

Cumulative characteristics of technology give rise to the following two propositions regarding countries' technological specialization patterns. (1) The majority of technological changes are cumulative or path-dependent processes, and the patterns of technological specialization are stable for a fixed period of time. (2) Technological change is an incremental process, and the sectoral composition of innovation may shift in the long term.

The investigation of these propositions has mainly been conducted with respect to the developed countries of Europe and the United States. These results confirmed that the path of technological development differs in each country, and aside from Laursen (2000), that the degree of technological specialization generally increases for most countries, that is, it is cumulative.

The point of note is that, regardless of the recent expansion in innovative capabilities exemplified by the rapid increase in the number of patents in East Asian NIEs such as South Korea and Taiwan, there has been absolutely no research regarding dynamic changes in technological specialization patterns in East Asia. In terms of the propositions above, there is almost no existing research that responds to inquiries such as the following. (1) Are the technological specialization patterns in East Asia stable due to path dependent patterns or cumulative patterns reflecting prior learning or technological accumulation? Or, are they stuck in random patterns under which the sectors of specialization periodically switch, without advancing the accumulation of technology? (2) Does the incremental process of technological specialization cause shifts in the sectoral composition of innovative sectors in the long term?

In order to respond to the inquiries above, in this paper a statistical investigation was conducted using U.S. Patent and Trademark Office (USPTO) patent data for 10 East Asian countries and regions (Japan, South Korea, Taiwan, Singapore, Hong Kong, Thailand, Malaysia, The Philippines, Indonesia and China). In section 2, the data used and analysis methods are explained. Next, in section 3 the results of analysis are discussed, and lastly the main conclusions are presented.

2. Empirical Analysis: Data and Methodology

2.1 Data

In this study, the original data used for the calculation of all technological indices are from the USPTO database, in which the patented inventions are grouped in about 400 main (3-digit) patent classes, though the classification system actually contains thousands of subclasses. Even 400 classes are far too many for our analysis, and hence we use a higher-level technological classification developed by Hall et al. (2001), according to which the 400 classes are aggregated into 36 two-digit technological sub-categories, and these in turn are further aggregated into 6 main categories. We divide the entire period of 31 years from 1975 to 2005 into three consecutive 10-year periods based on the grant year (1975-1984, 1985-1994, 1995-2005) in order to reduce the erratic year-to-year variation in the data (i.e., the number of patents per country and technology fields in each period is large enough to avoid large fluctuations in the values of indices).

2.2 Methodology

The revealed comparative advantage index is a numerical reference by which to measure the specialization occurring in trade. This was first applied to technology by Soete (1987), and is known as the revealed technological advantage index (RTA) index. The RTA index for country i in sector j is defined as the ratio of country i's share of total world patents in sector j to country i's share of total world patents, i.e.

$$RTA_{ij} = \left(n_{ij} / \sum_i n_{ij}\right) / \left(\sum_j n_{ij} / \sum_i \sum_j n_{ij}\right) \qquad (1)$$

where n_{ij} is the number of patents of country i in sector j. By definition, if the country holds the same share of worldwide patents in a given technology as in the aggregate, this index equals 1, and is above (below) 1 if there is a relative strength (weakness). The RTA index has been used in much research attempting to reveal the technological specialization patterns in sectors. However, it is inappropriate to conduct regression analysis using this index when the absolute number of patents in an individual country is small.

In order to conquer the issue, the value of the RTA index is modified and normalized as follows, according to Dalum et al. (1988) and Laursen (2000).

$$RSTA_{ij} = \left(RTA_{ij} - 1\right) / \left(RTA_{ij} + 1\right) \qquad (2)$$

Equation (2) is known as the revealed symmetric technological advantage (RSTA) index, and takes a value between -1 and 1. When RTA_{ij}=0, $RSTA_{ij}$= − 1, when RTA_{ij}=1, $RSTA_{ij}$=0 and when $RTA_{ij} > 1$, the larger the value of RTA_{ij}, the closer $RSTA_{ij}$ draws to 1. Thus, if $RSTA_{ij} > 0$ then the country i is relatively specialized in sector j.

Galtonian Regression Model

According to the theory of technological accumulation, the distribution of the RSTA index is stable over the time. The correlation between the distributions of RSTA indices for sectors during two periods is estimated by means of the following simple cross-section analysis.

$$RSTA_{ij}^{t2} = \alpha_i + \beta_i RSTA_{ij}^{t1} + \varepsilon_{ij}^{t2} \qquad (3)$$

where i represents a country (i=1,.......,10), j represents the sector of industry (j=1,.....,36), α and β are standard linear regression parameters, and ε is a residual term. The superscripts t1 and t2 refer to two different periods of time. The dependent variable, *RSTAij* at time t2, is tested against the independent variable, which is the value of *RSTAij* in the previous time t1. In equation (3), the two most distant periods are first considered (t1: 1963-74, t2: 1995-2005), in order to capture the dynamic aspect of the changes in the RSTA. Consideration is then paid to the period 1975-85 with respect to 1995-2005, and lastly to the closest periods, 1985-94 with respect to 1995-2005.

β-specialization and Regression effect

The estimated results can be interpreted as follows. Firstly, $\hat{\beta} \geqq 1$ is the condition under which cumulativeness in the sectoral distribution of innovation outweigh incremental change. Within this condition, if $\hat{\beta} = 1$ then the RSTA distributions for the two periods are perfectly cumulative, and there are no structural changes during the two periods. The ranking of the industrial sector therefore does not change. This not only means that technologically specialized and de-specialized sectors experience respectively no further specialization nor change in degree of minority, but also that they are each fixed in exactly the same position during the two periods. This proposition is investigated with $H_0: \hat{\beta} = 1$. In the case that $\hat{\beta} > 1$ on the other hand, while the accumulation pattern is intensified and the specialized sectors are further enhanced, de-specialized sectors also become further subordinated. This has been termed β-specialization by analogy to the convergence literature (Dalum et al., 1998, Laursen, 2000).

The next case is that of $0 < \hat{\beta} < 1$, which represents a combination of incremental change and cumulativeness in the pattern of technological specialization. By the same analogy as above, this is termed β-de-specialization. In this case, while the specialized sectors recede, de-specialized sectors improve their position. This is what has been termed 'regression towards the mean' (Hart, 1976). As a consequence, $(1 - \hat{\beta})$ becomes a measure of the size of the so-called 'regression effect', and an interpretation of the estimated coefficient β. That is to say, the closer β draws to zero, the larger the regression effect. However, it is should be noted that the specialized and de-specialized sectors grow closer to one another, but this does not mean that the relationship between them is reversed, and the actual ranking of each sector does not change. In addition, the test of whether $\hat{\beta}$ is significantly larger than zero ($\hat{\beta} > 0$) is a test of the properties of accumulation against the proposition that the sectoral composition of innovation is random (in this case, $\hat{\beta} = 0$). This is investigated using a t-test with respect to H_0: $\beta = 0$.

Lastly, in the special case of $\hat{\beta} < 0$, the ranking of sectors is reversed at the 2 points in time, in opposition to the anticipated cumulativeness of technological specialization. Those RSTAs initially below the country average are above average in the final period and vice versa. If $\hat{\beta} \leqq 0$ then the hypothesis that a country's technological specialization pattern is reversed ($\hat{\beta} < 0$) or is random ($\hat{\beta} = 0$) cannot be rejected.

σ-specialization

The degree of technological specialization in a country can be measured by the variance of its RSTA index. Pavitt (1988) used the standard deviation of the RTA index as an indicator of such specialization. Soete's (1987) original work also analyzed the variance of the RTA index.

We follow the method of Hart (1976) to estimate the changes in the variance of the distribution. With reference to Hart (1976) it can be shown that:

$$\sigma_i^{2t2} \Big/ \sigma_i^{2t1} = \beta_i^2 \Big/ R_i^2 \qquad (4)$$

Where σ^{2t1} and σ^{2t2} are the variances at time t1 and t2, respectively. R^2 is the square of the correlation coefficient from the regression set up in Equation (3) above. From equation (4), it can be seen that the degree of technological specialization increases in the case that $\beta^2 > R^2$, and decreases in the case that $\beta^2 < R^2$. A high variance indicates a high or narrow degree of technological specialization, and a low variance indicates that the country has either a broad range or low degree of technological advantages. If the values of the estimated coefficient of regression are used, the degree of specialization rises where $|\hat{\beta}| > |\hat{R}|$ (equivalent to an increase in the variance), and falls where $|\hat{\beta}| < |\hat{R}|$ (equivalent to a decrease in the variance). Further, in the case that $|\hat{\beta}| = |\hat{R}|$, the degree of specialization does not change. Of these cases, $|\hat{\beta}| > |\hat{R}|$ may be referred to as σ-specialization by analogy with the convergence literature, and $|\hat{\beta}| < |\hat{R}|$ may be referred to as σ-de-specialization (Dalum et al., 1998, Laursen, 1990).

Mobility Effect

The estimated Pearson correlation coefficient $\hat{R}$ is a measure of the mobility of sectors up and down the RSTA distribution. A high value of $\hat{R}$ indicates that there is little change in the relative positions of the sectors, and a low value of $\hat{R}$ on the other hand, indicates that some sectors are moving closer together and others further apart, quite possibly to the extent that the ranking of sectors changes. Here, the size of $(1-\hat{R})$ thus measures the so-called 'mobility effect', and a large mobility effect means that the ranking among sectors changes.

3. Estimation Results

Table 1 shows the estimated results of regression of the RSTA index in 1995-2005 on the index in 1975-84 for each country.

Firstly, $\beta = 0$ is rejected at the 1% or 5% level for Japan, Taiwan, Hong Kong, Singapore and Indonesia, but may not be rejected for the remaining 5 countries (South Korea, China,

Table 1. The development of technological specialization patterns 1975-2005 for 10 East Asian economies (n=36sectors)

	1975-84 to 1995-05			
	β	β/R	(1-β)	(1—R)
Japan	0.905^{**}	1.06	0.10	0.15
Taiwan	$0.498^{**\#\#}$	0.80	0.50	0.38
Hong Kong	$0.256^{*\#\#}$	0.68	0.74	0.63
Korea	$-0.096^{\#\#}$	0.79	1.10	1.12
Singapore	$-0.204^{*\#\#}$	0.57	1.20	1.36
China	$0.038^{\#\#}$	0.37	0.96	0.90
Malaysia	$0.047^{\#\#}$	0.55	0.95	0.91
Thailand	$0.122^{\#\#}$	0.68	0.88	0.82
Philippines	$0.026^{\#\#}$	0.90	0.97	0.97
Indonesia	$0.458^{*\#}$	1.28	0.54	0.64

Note: The degree of specialization=β / R, the regression effect = (1-β), and the mobility effect = (1-R).
** denotes significantly different from zero at the 1% level.
* denotes significantly different from zero at the 5% level.
denotes significantly different from unity at the 1% level.
# denotes significantly different from unity at the 5% level.

Malaysia, Thailand and the Philippines). That is to say, while the technological specialization occurring in the two periods for the 5 remaining countries retains the random pattern, Japan, Hong Kong, Taiwan and Indonesia moves into a β-de-specialization pattern of cumulative and incremental change ($0 < \hat{\beta} < 1$) from 1975-84. On the other hand, although $H_0 : \beta = 0$ is rejected at the 5% level only for Singapore, the value of $\hat{\beta}$ is $\hat{\beta} < 0$ and the possibility that the technological specialization pattern of Singapore is reversed between the two periods is high, contrary to the hypothesis of cumulativeness. That is, the specialization patterns for the periods 1975-84 and 1995-2005 are very different.

Regarding the presence or absence of the path dependent specialization pattern indicated by Arthur (1988), $H_0: \beta = 1$ can be rejected in all cases except Japan. That is to say, the value of β for Japan is 0.905 and $0 < \hat{\beta} < 1$, but since this is close to 1 it could be said that rather than having a cumulative and incremental specialization pattern, the distributions of the RSTA index in the two periods indicate mostly identical cumulative and path-dependent specialization patterns.

This may be reconfirmed according to the fact that the value of $\hat{\beta}/\hat{R}$, which indicates the degree of technological specialization, is 1.06

Table 2. The development of technological specialization patterns 1985-2005 for 10 East Asian economies (n=36sectors)

	1985-94 to 1995-05			
	β	β/R	(1-β)	(1—R)
Japan	0.958^{**}	1.02	0.04	0.06
Taiwan	$0.822^{**\#}$	0.91	0.18	0.10
Hong Kong	$0.605^{**\#}$	0.81	0.40	0.25
Korea	$0.837^{**\#}$	0.96	0.16	0.13
Singapore	$0.364^{**\#\#}$	0.86	0.64	0.58
China	$0.251^{*\#\#}$	0.70	0.75	0.64
Malaysia	$0.334^{**\#\#}$	0.60	0.67	0.44
Thailand	$0.271^{**\#\#}$	0.59	0.73	0.54
Philippines	$0.109^{\#\#}$	0.82	0.89	0.87
Indonesia	$0.366^{*\#\#}$	1.02	0.63	0.64

Note: The degree of specialization=β / R, the regression effect = (1-β), and the mobility effect = (1-R).
** denotes significantly different from zero at the 1% level.
* denotes significantly different from zero at the 5% level.
denotes significantly different from unity at the 1% level.
# denotes significantly different from unity at the 5% level.

for Japan, which is also quite close to 1. Regarding the degree of technological specialization in the other countries, only Indonesia has $\hat{\beta} / \hat{R} > 1$, indicating σ-specialization (a specialization pattern in which the degree of specialization increases or the range is narrowed), and the reverse, σ-de-specialization (a specialization pattern with a broad range), for the rest.

Finally, the results regarding the periods 1985-94 and 1995-2005 are as follows (Table 2). At this stage the hypothesis $H_0: \beta = 0$ is rejected at the 1% or 5% level in all cases except the Philippines. Entering these periods, only the Philippines still retains a random pattern of specialization, and a β-de-specialization pattern of cumulative and incremental specialization can be seen in all the other countries, showing a 'regression towards the mean'. However, for Japan alone, $H_0: \beta = 1$ cannot be rejected for these periods of analysis (1985-94 and 1995-2005). That is, for Japan, $\hat{\beta}$ is not significantly different from one (which amounts to a test on whether the regression effect, $1-\hat{\beta}$, is significantly different from zero). This reveals that since 1975-84 Japan has remained a cumulative and path-dependent technological specialization pattern. Also, the value of $\hat{\beta}/\hat{R}$ reflecting the degree of technological specialization is 1.02 for Japan, which is even closer to 1 than in the previous periods of analysis, that is, the variances of the two periods are almost equal, and it can be seen that the pattern of technological specialization has become fixed.

Regarding the change in the degree of technological specialization in the other countries for 8 of 9 countries, excepting Indonesia, the value of $\hat{\beta}/\hat{R}$ is smaller than 1, and the regression effect exceeds the mobility effect. This means that there has been a tendency for the degree of technological specialization to fall over the past 20 years (σ-de-specialization or broad specialization). Aside from Japan and Indonesia, in the remaining 8 countries the decrease in the degree of technological specialization reflects the fact that the number of patents increased across a broad range of sectors in the period 1995-2005 with respect to 1985-94. However, among the 8 countries for which the degree of specialization decreased, excluding Thailand and the Philippines, the values of $\hat{\beta}/\hat{R}$ for Taiwan, Hong Kong, South Korea, Singapore, China and Malaysia increased even more than for the previous periods of analysis (1975-84 and 1995-2005), from which it can be seen that the degree of technological specialization had an increasing tendency in these 6 countries. On the other hand, it can also be seen that there was even more of a decreasing tendency in the degree of specialization in Thailand and the Philippines.

According to the analyses above, it can be seen that Japan, Hong Kong, Taiwan and Indonesia entered cumulative and incremental specialization patterns from the period 1975-84, while South Korea, Singapore, China, Malaysia and Thailand entered since the period 1985-94 (prior to which they had random specialization patterns). Japan maintained a path-dependent specialization pattern under which the RSTA distributions and variances did not change over the two periods, since 1975-84. In Singapore the specialization patterns for the two periods of 1975-84 and 1995-2005 were reversed, but from 1985-94 the pattern moved into cumulative and incremental specialization pattern. Finally, only the Philippines still maintains a random pattern. These facts make clear the following. Firstly, for the period analyzed, in East Asia there were no cases of $\beta > 1$, which would indicate that a cumulative pattern was enhanced (β-specialization). Secondly, many of the countries had a predominantly random pattern from the mid-1970s to the first half of the 1980s during which the number of patterns was small. Thirdly, since the mid-1980s, many countries experienced an increase in numbers of patents and simultaneously moved into a cumulative and incremental specialization pattern (β-de-specialization). This accords with Cantwell's (1989) conclusion that 'the statistical evidence on international sectoral patterns of technological advantage offers support to the idea that innovation tends to unfold as a cumulative process, accompanied by gradual incremental change'.

Regarding the change in the degree of technological specialization, since the mid-1970s, the degree of specialization increased in only Indonesia and Japan (although Japan was mostly homoscedastic), and the opposite, σ-de-specialization, was demonstrated by the other 8 countries. According to Cantwell's (1991) analysis which used the RTA with respect to the OECD countries with 27 sectors, an increase in the degree of technological specialization over the periods 1963-69 and 1977-83 was seen in 11 of 19 countries. According to the analysis by Archibugi and Pianta (1992) of the OECD countries using the RTA with 41 sectors, an increase in the degree of specialization was seen over the periods 1975-81 and 1982-88 for 11 of 16 countries. On the other hand, under the analysis of the OECD countries using the RSTA with 19 sectors by Laursen (2000), an increase in the degree of specialization over two sub-periods (1971-73 and 1980-82, together with 1980-82 and 1989-91) was seen in, respectively, 11 and 10 of 19 countries, but over the whole period (1971-73 and 1989-91) an increase in the degree of specialization occurred in only 6 of the 19 countries. It can be seen from the analyses of the developed countries that the degree of technological specialization increased in many of these countries. In contrast, the research presented in this paper reveals a decreasing degree of specialization for most countries. Regarding this point, the results indicate that the number of patents from what was originally a small number has expanded from a narrow to a broader range of sectors in the periods analyzed. This can also be seen from the fact that the average annual growth rate in the number of U.S. patents granted for the East Asian region, excluding Japan, greatly exceeded that of the developed countries. This occurred together with a cumulative and incremental technological specialization pattern, that is, a combination of β -de-specialization and σ -de-specialization. However, in the final analysis period while many of the countries experienced σ -de-specialization, an increase in $\hat{\beta} / \hat{R}$ suggests that the degree of technological specialization in East Asia may increase in the future (towards σ -specialization) in accordance with the theory of technological accumulation.

4. Concluding Remarks

This paper statistically investigated three propositions regarding the pattern of technological specialization for 10 countries in East Asia using patent data. The results obtained from this research are as follows.

(1) By the latest period (1985-94 and 1995-2005) at least 8 of the 10 countries in East Asia had moved from a random technological specialization pattern to a cumulative and incremental pattern reflecting technological accumulation. On the other hand, since 1975-84 Japan moved from its previous cumulative and incremental pattern to a cumulative and path-dependent technological specialization pattern. Only the Philippines maintained a random technological specialization pattern for all the periods.

(2) Regarding the change in degree of technological specialization, most of the countries exhibited specialization over a broad range (σ -de-specialization) in parallel with an increase in the number of U.S. patents. Also, based on the fact that the regression effect exceeded the mobility effect for many of the countries, the decrease in the degree of technological specialization was achieved in parallel with a stable pattern of specialization sectors. In the case of Japan, the degree of technological specialization remained mostly unchanged, reflecting a path-dependent technological specialization pattern.

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