The Evolution and Pathways for Development: Science and Technology of NIEs and Selected Asian Emerging Countries

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Abstract

Many emerging countries in Asia demonstrate a strong pattern of growth and potential of diffusion in science and technology that is dynamic and self-propagating. To elucidate the evolution in science and technology and the institutional dynamics that drive the self-propagating behavior, this paper attempts to examine the national science and technology pathways and accumulated knowledge stocks of selected economies in Asia. An analysis of papers and patents production for each nation was conducted to examine the indigenous science and technology capabilities. To enrich knowledge on self-propagating behavior for different stages of industrialization, this study focused on six major economies, namely China, Malaysia, South Korea, Singapore, Taiwan and Thailand. In addition, Japan, a country with advanced development of science and technology, is included for comparison. The findings provided insight and understanding of evolving science and technological waves and the dynamic potentials in science and technology. We demonstrate the institutional dynamics that drive the self-propagating behavior, thus providing a more complete understanding of the innovation systems than those examined in previous studies.

Keywords: Asian countries, papers and patents, science and technology, self-propagating behavior

1. Introduction

The role of science and technology in driving productivity and economic growth is given emphasis in the ‘new growth theory’ in which knowledge is central to economic development (OECD, 1996). Many Asian countries experienced a shift from agriculture and primary commodities dependent economy to manufacturing based and export driven economy, and subsequently progressing towards post-industrial knowledge-based economy (Choung and Hwang, 2000, Park et al., 2005, Nagano, 2006, and Asgari and Wong, 2007). The newly industrialized economies (NIEs) like South Korea, Taiwan and Singapore and developing
countries like China, Malaysia and Thailand\textsuperscript{1} had witnessed commitment of resources towards building science and technological production capabilities with potentials of economic rents derived from innovations that can shield them from price and cheap labour cost competition in the global market.

Our previous findings (see Wong and Goh, 2009, 2010a and 2010b) had traced the self-propagating growth behaviour in the evolution of science and technology of selected countries in Asia including the NIEs that stems from the virtuous growth cycles between science and technology. Continual investment in science and technology had led the NIEs to demonstrate a strong self-propagating behavior that pushes the development towards knowledge-based economic growth. The mechanism of science and technology evolution suggested co-evolution between the production of new knowledge and its potential of development. The empirical findings provide insight for understanding the evolving science and technological waves and the dynamic potential of the carrying capacity in the selected Asian countries which are evidence of growing potential of science and technology. The conceptual framework of our study is largely based on the national innovation system approach, and our preceding work does not offer a detailed analysis on the efforts taken by each of the selected countries to promote science and technological activities and initiatives to enhance the institutional capabilities.

In this paper, we attempt to provide a detailed analysis of the evolution and pathway taken by selected Asian countries to achieve development in science and technology. In particular, we focus on publications and patents (in meso-scale) to assess the competencies of science and technology capabilities. We aim to capture the historical evolution of the national innovation system and strategies that shaped science and technology activities and built science and technology capabilities. The trends of science and technology growth as well as the related development strategies can be used to elucidate the cumulative nature of the learning processes,\textsuperscript{2} and the process of accumulation of science and technological knowledge is useful for assessing the vitality of science and technological production as a result of the systemic effects of individual countries. Very few have ventured to study national innovation system with the use of science and technological stock as a measure of vitality of science and technological development. This study examines the importance of knowledge stock in science and technology in ascertaining the vitality of growth. In order to cover the experience of different stages of development, this study follows Wong and Goh (2009) in selecting six economies, namely China, Malaysia, South Korea, Singapore, Taiwan and Thailand for analysis. Japan, a country with advanced development of science and technology, is included for comparison.

In the second section of the paper, a synthesized framework of analysis is proposed. Section 3 employs cross-section data collected on 67 countries to gauge some indication on the threshold levels that trigger an interactive relationship between the input and output of national innovation system. Drawing upon the empirical results, a comparative analysis is conducted to explore the extent of cross country differences in science and technology capabilities. Section 4 provides an analysis on the pathway taken by the selected countries to understand why the NIEs

\textsuperscript{1} The science and technology development path of these countries had many similarities in their evolution trajectories, technological option and avenue of innovation (see Fagerberg \textit{et al.}, 2007 p. 1602, Dowling and Valenzuela, 2010 p. 160).

\textsuperscript{2} The learning processes are most likely to generate self-propagating behaviour of science and technology activities (Malerba \textit{et al.}, 1997). Therefore, the historical development of science and technology charters the direction of the cumulative learning processes as well as the related competencies of a nation (Lundvall, 1992).
excelled in science and technology development while the others continued to be trapped in a less-developed stage.

2. Framework of Analysis
According to Rosenberg (1994), a systematic examination of the sequence of events which constitutes the history of the national innovation system is required for revealing and understanding the features of science and technological propagating behavior. This will provide an integrated picture of the sources (institutional dynamics) that lead to success in science and technology development.

Hu and Mathews (2005) and Hu and Tseng (2006) maintained that the national innovative capacity is highly dependent on knowledge stock, R&D workforce, R&D investment and specialization in science and technology. These are recognized as institutional factors, and they are essential for driving the growth of science and technology. This section discusses the framework for examining the systemic mechanism that induces science and technology vitality, and to trace the distance between and changing level of production of the selected Asian countries.

2.1 Production of Science and Technology
Before the analysis on the individual countries is conducted, we attempt to understand the importance of investment in R&D in the generation of science and technology output. The relationship is typically that of a production function, \( \ln Y = f(\ln X) \), with R&D investment as the input \((X)\), and the science and technology production as the output \((Y)\). In this paper, the number of papers and patents produced are employed as the proxy for output of science- and technology-based activities respectively. The input for the production function of science is the R&D investment of the institutions of higher learning (IHL), while the input for the production function of technology is the private sector R&D investment. To estimate the production function of science (technology), number of papers per million population (number of patents per million population) were regressed on the ratio of IHL R&D investment to GDP (the ratio of private sector R&D investment to GDP). A cross-country dataset was used for the estimation and the production functions were compared over two period of time, i.e., 1996 and 2006. All the series were transformed into logarithms prior to estimation.

2.2 Comparative Analysis
The resources (inputs) for the formation and perfection of the innovation system and production (outputs) of science and technology are central for knowledge-based economic development. Input and output indicators are useful for examining the dynamics of the innovation system in developing and diffusing new science and technology. To conduct the comparative analysis of the selected Asian countries, we employed the following indicators:
   (a) Input Indicators
      - The ratio of R&D expenditure to GDP

3 Institutions as the driving forces to the growth of publications and patents of the NIEs are essential for national innovation development.
- The number of full-time equivalent (FTE) of R&D workforce per million population

(b) Output Indicators
- Number of publications per million population
- Number of patents per million population
- The ratio of number of patents to number of papers (for measuring concomitant growth of science and technology)

The indicators for each nation are presented using a radial plot to compare the strengths of science and technology among the selected countries. The input and output indicators for Japan are used as the benchmark in the plot and their radials were set to one. The value of each indicator of the other economies was divided by the corresponding value for Japan. The distance of the indicators between the selected Asian countries and Japan was traced through the radial plot.

The cross-country dataset was used to examine the relationship between the number of patents per million population and real GDP per capita. The relationship allows an assessment of the position of the selected Asian economies in terms of technological catch-up within the context of economic growth in comparison to other countries.

A meso-scale analysis of paper and patent production was conducted to elucidate the national indigenous science and technology capabilities. The analysis that includes the papers published by field of science and the patents granted by field of technology also elucidates the structure of science and technology.

2.3 The Changing Level of Science and Technology Production

According to Lundvall (1992), Malerba et al. (1997), Watanabe et al. (2001), and Han (2007), the production of new science and technology is strongly dependent on the accumulation of science and technological stock due to the path-dependent nature. The analysis of this nature provides a coherent phenomenon of self-propagating behaviour in the development of science (technology). Therefore, the following function stated below is of the most common form to estimate the changing level of science and technological knowledge stock (see Lach, 1995, Tarasyev and Watanabe, 1999, Esposti and Pierani, 2003 and Han, 2007) is used in this study:

\[
KS_t = T_{(t)} + (1 - \sigma)T_{(t-1)}
\]  

Scientific or technological stock is dependent on the stock in the previous year with a depreciation of learning efficiency (\(\sigma\)) and the knowledge input (\(T_{(t)}\)) which proxied by papers and patents published (granted) in year \(t\). The following function expresses the sum of knowledge from the base year \((b)\) to \((t)\):

\[
KS_t = T_{(t)} + (1 - \sigma)T_{(t-1)} + (1 - \sigma)(1 - \sigma_{t-1})T_{(t-2)} + \ldots + (1 - \sigma)\ldots(1 - \sigma_{(t-b)})T_{(b)}
\]
Given the knowledge stock function is estimated from cumulative forms of knowledge input with the average growth rate \(g_{avg}\) across all time, knowledge stock at the base year can be obtained with the following function:

\[
KS_b = \frac{1 + g_{avg}}{g_{avg} + \sigma} T(b)
\]  

(3)

This study used the obsolescence rates obtained from Wong and Goh (2009) as the rate of depreciation to postulate that research investment becomes fully effective after a given number of years (gestation period). The assumption is in accordance with that of the existing methods for measuring \(\sigma\) (see Pakes and Schankerman, 1984, Adams and Griliches 1996, Esposti and Pierani, 2003, and Park and Park, 2006).

The estimated knowledge stock of an economy explains the capacity to assimilate and utilize the accumulated knowledge for production of science and technology. According to Hur and Watanabe (2001 and 2002), assimilation capacity (AC) would be expected to increase as knowledge stock increased. The prolonged growth of knowledge stock (see Figure 1) is attributed to the new knowledge, in response to linkages among institutions for production of science and technology. Figure 2 explained the mechanism.

![Figure 1: Accumulating Process of Knowledge Stock.](source: Adapted from Hur and Watanabe (2002).)

### 2.4 Data Source

The data are the historical series of ISI publications from 1981 to 2005 (ISI, 2005) and patents granted from the US Patent and Trademark Office from 1984 to 2004 (USPTO, 2005) for China, Japan, Taiwan, South Korea, Singapore, Malaysia and Thailand. The ISI database covers the world leading journals of science and the USPTO patents are useful indicator of technological activities. This study assumes that the selected economies have high tendency to patent their inventions and innovations in the US Patent and Trademark Office, as it is the major centre for

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4 The document provides details of inventive and innovative activities (Bhattacharya, 2004).
registering the patents of many developed and developing countries (Bhattacharya, 2004 and Schmoch, 2009). In addition, this approach helps to prevent the home bias effect\(^5\) that could be observed in using data from national patent offices (Dachs et al., 2007). The ISI publications cover all the fields of sciences, including natural, physical, health and social sciences\(^6\). Patents are recorded by grant year. The reasons for using these data are their availability and completeness for analysis, and comparability across different countries.\(^7\) The cross-country dataset was obtained from UNESCO (2009) and UNSTATS (2009), while some of the related Taiwan and Malaysia data were extracted from MOSTI (2008) and IMF (2009) respectively. This dataset includes information on GDP and R&D investment. The statistics for the input and output indicators were also taken from this dataset. The dataset covers many countries, but only those with publications and patents were included in the analysis. Between 41 to 67 observations were used in the estimation, and the number depends on data availability and the year of analysis.

\[
KS_t = T_{(t)} + (1 - \sigma)T_{(t-1)}
\]

**Figure 2: The Mechanism of Knowledge Stock.**

Source: Adapted from Hur and Watanabe (2002).

3. **Growth of Science and Technology Over Time**

The significance of R&D inputs for science and technological innovation is examined in this section. The empirical results allow an assessment of the distance of production of science and technology between the selected Asian economies. We also attempt to conduct a comparative analysis among the selected economies to identify the trends of growth and the competency of each national innovation system within the dimensions of science and technology knowledge.

3.1 **Production of Science and Technology**

\(^5\) Many inventors have the tendency to apply for patents at the home patent office. The internal influence is highly attributed to the competitive environment in the US market. On the other hand, many Asian firms (local or MNCs) seek protection for their innovation to compete in the US market.

\(^6\) The share of papers in the field of social sciences and humanities of the total publications is low. The share for the selected countries is approximately between 1.7 to 3.8 percent.

\(^7\) We admit the shortcomings of the data, including the exclusion of the rejected applications that were also contributing to the innovation activities, and the time lag between application and approval that may misrepresent the actual year an innovation is made. The information, however, is not available.
The regressions of the output (papers and patents) on R&D investment were estimated and the results are reported in Table 1. The production increased significantly with higher input into the innovation system for both science and technology, and this relationship holds over time. The adjusted $R^2$ for both the regressions increased from 1996 to 2006, suggesting that the relationship between science and technology output and R&D input grew stronger over the years. Generally, a one percent growth in input to innovation generates almost 1.12 and 2.05 percent increase in the number of papers and patents respectively for 2006. While the output elasticity remains about the same for science, the elasticity increased for technology. The R&D investment had a larger impact on technology as time progresses with stronger institutional establishments. In addition, the higher value of the intercept of the regressions for 2006 compared to 1996 show rising science and technology achievement on average.

### Table 1: Science and Technology Output, 1996 and 2006

<table>
<thead>
<tr>
<th>Year</th>
<th>Coefficient of R&amp;D Investment</th>
<th>Constant</th>
<th>n</th>
<th>F</th>
<th>Adj. $R^2$</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>1.16 (7.29)</td>
<td>12.65 (12.32)</td>
<td>46</td>
<td>53.07</td>
<td>0.53</td>
<td>1.76</td>
</tr>
<tr>
<td>2006</td>
<td>1.12 (12.68)</td>
<td>12.83 (22.19)</td>
<td>47</td>
<td>160.80</td>
<td>0.77</td>
<td>1.67</td>
</tr>
<tr>
<td>Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>1.54 (8.34)</td>
<td>9.77 (9.21)</td>
<td>53</td>
<td>99.64</td>
<td>0.57</td>
<td>1.69</td>
</tr>
<tr>
<td>2006</td>
<td>2.05 (15.91)</td>
<td>12.77 (17.54)</td>
<td>56</td>
<td>230.97</td>
<td>0.81</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Note: Figures in parentheses are t-statistics. For science, the dependent variable is number of papers per million population, and the independent variable is ratio of IHL R&D investment to GDP. For technology, the dependent variable is number of patents per million population and the independent variable is ratio of private sector R&D investment to GDP.

### 3.2 A Comparative Analysis of the Selected Asian Countries

Generally, the earlier regression analysis indicates that investments in R&D to promote science and technology activities are likely to yield success in the race for acquiring innovation rents and economic development. Among others, sound institutional practices and governance that foster persistency in science and technology activities are means to address the rising resources required to achieve economic growth. According to Nelson (1993), Wong (1999) and Fagerberg

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8 The findings support the theoretical propositions of Nelson and Winter (1982) and Malerba et al. (1997).
9 Commitment and intervention of the national government (as the lead role in allocation of resources) in the industrial and financial sector is vital to support growth and development. The outstanding pace of economic growth in Asian emerging countries is discussed in Dowling and Valenzuela (2010, p. 31).
et al. (2007), the strong development of South Korea, Taiwan and Singapore could be attributed to their commitment to develop science and technology institutions in the early catching-up process. The NIEs moved ahead prominently in science and technology, progressing further in their transformation to post-industrial knowledge-based economies.

According to Shulin and Lundvall (2006), an innovation system is defined as sets of institutions, which jointly and individually contribute to the generation and diffusion of knowledge. The inputs to the innovation system influence significantly the production of papers and patents. Figure 3 shows the inputs and outputs of the innovation system for the selected economies. Japan was used as benchmark (values set to 1 in the radial plot). As highlighted by Wong et al. (2007), the NIEs are advancing towards the adoption of knowledge-based strategy for the economic development. The radial of their inputs to the innovation system (FTE of R&D workforce per million population and the ratio of R&D to GDP) is symmetric or close in proximity to the case of Japan. The radials of the other countries are asymmetric to those of Japan, suggesting that the development in human capital and R&D investment are still lagging behind. However, it is worth noting that the R&D activities of China are far ahead of Thailand and Malaysia.

### Table 2: Impact of Technology on GDP, 1996 and 2006

<table>
<thead>
<tr>
<th></th>
<th>Slope Coefficient</th>
<th>Constant</th>
<th>n</th>
<th>F</th>
<th>Adj. $R^2$</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>0.46 (11.79)</td>
<td>8.47 (74.85)</td>
<td>60</td>
<td>139.49</td>
<td>0.70</td>
<td>2.08</td>
</tr>
<tr>
<td>2006</td>
<td>0.38 (10.37)</td>
<td>8.61 (76.39)</td>
<td>56</td>
<td>107.49</td>
<td>0.62</td>
<td>2.30</td>
</tr>
</tbody>
</table>

Note: Figures in parentheses are t-statistics. The dependent variable is real GDP per capita (log) and the independent variable is the number of patents per million population (log).

Positive interaction between science and technology will create self-propagating dynamics that advance the growth in their potentials. This is evident in the ratio of number of patents to papers of South Korea and Taiwan, suggesting an almost one-to-one relation between the science and technology production. Particularly in the case of Taiwan where the ratio was close to that of Japan, there is a strong interaction between scientific production and industrial applications. Many studies highlighted that interaction between the universities and industries in South Korea and Taiwan helped to promote the creation of science and technological output (Wong, 1999, Choung and Hwang, 2000, Bernadas and Albuquerque, 2003, Hu and Mathews 2005, Jan and Chen, 2006 and Nagano 2006). On the other hand, the ratio for Singapore and the other developing countries was relatively lower. These countries that are heavily dependent on foreign direct investment for technology development and economic growth could lag behind in commercializing new knowledge or science. These countries placed more priority on assimilation of foreign technologies in their human capital development than focusing on creation and commercialization of new knowledge through science and technological activities (Wong et al., 2007).

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10 The radial indicated the efforts of NIEs in developing their innovation system
The radials for patents per million population and papers per million population for the innovation system of the NIEs were close to the case of Japan. Noteworthy, Singapore overtook the production of Japanese papers and Taiwanese production of patents was very close to that of Japan. The brain gain-entrepreneurial university model of Singapore (Wong et al., 2007) and SMIs network model of Taiwan (Rasiah and Lin, 2005 and Nagano, 2006) had gained competence in science and technological production respectively. The paper and patent production of the other countries were different from those of Japan and the NIEs. Malaysia and Thailand, in particular, failed to acquire science and technological capabilities that are comparable to the NIEs in response to the changing economic climate.

The radial plot shows that the NIEs, specifically South Korea and Taiwan, experienced technology and innovation advancement that almost catches up with that of Japan. This could be due to the strong and mutually reinforcing relationship between science, technology and the market. Patent reflects the interest in commercial exploitation of a new technology. It would be of interest to look at the impact of technology on economic growth. The results in Table 2 show the results for the log-linear model between the number of patents per million population on real GDP per capita estimated on the cross-country dataset. The relationship between the two variables remained statistically significant over the years. The scatter plots for these variables are given in Figure 4 and Figure 5. The plots suggest a positive linear relationship. Along this linear line, we classified the countries under two categories, those moving ahead and those falling behind. The mean of the variables demarcated the categories. The increased mid-point of the sample means indicate the rising science and technological resources required to achieve the same economic growth over time. This is reflective of the results in Table 2 where the slope coefficient of the regression for 2006 is smaller than the corresponding value for 1996.

The upper left quadrant of Figures 4 and 5 covers the countries with above average level of real GDP per capita but below average level of technological (patents) production. Only very few countries were in this category, confirming that science and technology knowledge is an endogenous entity for development.

The lower left quadrant includes countries with below average level of per capita GDP and technological production. China, Malaysia and Thailand clustered in this category, particularly in 1996. Foreign science and technology remained the essential resources for development of these countries. The over reliance on foreign science and technology could obstruct the development of indigenous science and technology, thereby decreasing the ability of the national innovation system to generate self-propagating behaviour. However, the three countries have seen improvement in 2006, particularly Malaysia which is entering the border of the quadrant for catching-up economies. From the earlier radial plot, it can be observed that the ratio of patents to papers for China, Malaysia and Thailand has increased over the years. These developing countries have potentials for high growth, and witnessed commitment in building connections, interactions and multidirectional causal links among institutions. These findings also suggest that as the technological production grows, the capacity of the industrial sector to utilize scientific knowledge for development increases.

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11 This approach is introduced by Fagerberg et al. (2007) to identify the differences in economic performance across countries over time.
There is hardly any observation in the lower right quadrant of the figures. This would be the case as the possibility of countries with high and growing technological capabilities but failing to achieve growth is negligible.

The upper right quadrant consists of countries that gained development from high technological capabilities. Most countries in this trajectory were likely to have experienced the benefits of virtuous cycle between science, technology and economic growth. Growth is the result of the persistence of science and technology activities that are churned from technological competencies. Japan and the NIEs appeared to have much to gain from this interaction. On the other hand, Japan seemed to be moving closer to the border of the catching-up quadrant compared to its previous position. Perhaps some aspects of diminishing marginal returns have set in as the economy matures. The results of Wong and Goh (2009) that show the tapering of the country’s science and technology self-propagating potentials provide further support for this finding. In addition, expensive research activities in advanced countries may have led to lower productivity in scientific publications and patenting activities (see Kostoff 2008).

Note: All the data are obtained from MOSTI (2008) and UNESCO (2009). The data are for 2006 except for papers per million population which is based on the figure for 2005.
Figure 4: Relationship between GDP and Patents, 1996

Note: Doted lines indicate sample average.

Figure 5: Relationship between GDP and Patents, 2006

Note: Doted lines indicate sample average.
4. The Pathway to Development: Individual Country Experience

This section elaborates on the approach national institutions have taken to shape and charter their unique pathway to science, technology and economic development for each of the selected economy. The order of discussion proceeds from the NIEs to the developing countries.

4.1 South Korea

The South Korean strategy for technological development is to build up the process capability in the initial stage, then followed by the mastering of sophisticated products through imitative R&D. Foreign knowledge and technology was the main source for technological catch-up during the 1960s of the local firms. Universities in Korea played a minor role in the innovation system during the 1960s and 1970s. The universities were upholding only the role of public education to build a national workforce in order to meet industrial demand.

To move up the value-chain of technology, South Korea practiced a state protection strategy, and mobilized resources targeted at chaebol firms to build technology capabilities and competencies, particularly during the infant stage of industrial development. The direct support for large chaebol firms not only facilitated them to develop their own products and selling under their own brands in the local market, but also enabled them to establish R&D capability to compete successfully in few global industries such as automobile, semiconductors, consumer electronics and telecommunication equipment. The government incentives and supports fueled entrepreneurial activities in the 1970s and 1980s, reduced risks by firms involved in costly investment for innovation, and stimulated R&D investments for science and technology (Wong, 1999, Lee, 2006 and Rasiah, 2007). Their dynamic technology policy led to systemic learning and catching-up with the western technology in most chaebol firms, which subsequently led to growing technological capabilities (see Yun, 2007).

The number of patents increased noticeably since the early 1990s (see Figure 6). This could be attributed to the efforts of the government in supporting chaebol firms to develop their technological capabilities during the 1980s. R&D investment incentives and supports from the government to induce applied research activities during the 1980s was favorable to chaebol firms to develop the value chain from assembly-based low value-added industries towards higher value added activities. Furthermore, the technology policy in the 1990s was established to support commercialization of new technologies, leading to a further boom since the mid of 1990s.

The total utility patents granted to Korea were 50427 for the period of 1963 to 2007. The trend of patenting activity indicated great interest in the technological sector that covers process, machine, and article of manufacturer or composition of matter. Most patents granted from the USPTO were to the electronic and semiconductor chaebol firms while the small and medium industries (SMLs) played only a minor role in the production of technology.

Due to the dominance of manufacturing and competency of the semiconductor, electrical and electronics firms in Korea, the semiconductor device manufacturing, static information storage and active solid-state devices were the three prominent fields of technology that recorded increasing number of patents. Emerging trends in the technology related to liquid crystal cells, television and computer graphics processing were also quite noticeable (see USPTO, 2008). The emerging trends of these technologies, labeled as science-based technology (see Grupp and Schmoch, 1992, Grupp, 1994, Grupp, 1996, and Krahmer and Schmoch, 1998), were made possible because of the strong research cooperation between the industries, universities and research institutions.
South Korea experienced a similar path of development with Japan where local conglomerate firms were selected as the main agent of development. The efforts of the government advanced the production of patents significantly over the years. In particular, Samsung Electronics outperformed the established firms in Japan, Taiwan and Singapore (see Table 3) in terms of patents production in 2007, although the number was lower compared to Toshiba, Japan in 2000. The emerging trend of Korean technology in semiconductors device manufacturing was quite visible, aggressively catching-up with the number of patents awarded to Japan (see Table 4).

![Figure 6: Utility Patents of the South Korea, Taiwan and Singapore](image_url)

The role of universities evolved from teaching and conducting basic research to commercializing their research outputs for the market (Choung and Hwang, 2000). Applied physics, condensed matters and materials science, material science and engineering and physics were the three prominent fields\(^\text{12}\) of scientific research activities in the universities that recorded increasing number of papers in the ISI database (see Figure 7) which supported the development of South Korean science-based technologies, particularly semiconductor and pharmaceutical and cosmetics technology (see Appendix 1 for concordance of key science disciplines with technology). Korea established a strong and extensive networked in their innovation system. The high participation of industries and public research institutions in university-driven scientific production activities suggest good orientation and adjustment of national institutions to reinforce the development of science and technology.

<table>
<thead>
<tr>
<th>Table 3: US Patents Granted to Research Institutions and Firms</th>
</tr>
</thead>
</table>

\(^{12}\) These fields were heavily funded by the government.
The function shown in Equation (1) is used to estimate the stock of science and technology production. See Figure 8 and Figure 9 for the plots of knowledge stock over time. The knowledge stock of South Korea in the early 1980s was low, comparable with that of many South East Asian countries. However, in the catching-up process, the South Korean knowledge stock was shown aggressively moving-up the science and technological value-chain. Its assimilation capacity (AC) is expected to increase significantly in response to the estimated stock. The process shows a great emerging potential of diffusion in science and technology due to its self-propagating behaviour. The science and technology growth stemmed from accumulated knowledge built over time, and its innovation system could reinforce the development of the new science and technologically dynamic industries such as chemical and biotechnology.
Figure 7: Total Number of ISI Papers of South Korea by Field of Science.

Figure 8: Scientific Knowledge Stock Over Time.
4.2 Taiwan

The Taiwanese firms adopted the Original Equipment Manufacturing (OEM)-Original Design Manufacturing (ODM)-Original Brand Manufacturing (OBM) strategy to develop their technology capability (Hou and Gee, 1993 and Wong, 1999). The strategy involved was to first develop the process capability through mastering of contract assembly operations (OEM), and this is followed by the development of sophisticated products through imitative R&D. Finally firms invested in R&D to develop their own products and technology processes (ODM). Many Taiwanese firms attempted to develop their own products which were marketed using their own brands (OBM). The Industrial Technology Research Institute (ITRI) was established by the government to support the technology development of electrical, electronics and semiconductor SMIs of Taiwan. Taiwanese firms gradually moved to higher value-added products and were involved in science-based technological R&D activities.

The complementing environment and leveraging consortia structure of institutions for research resources, in which ITRI engaged in industrial development and applied research, universities conduct basic research and industries commercialize R&D results led to significant development in knowledge based economy (Chang and Shih, 2004 and Phillips and Su, 2009). Since the success of ITRI, many Taiwanese from abroad, particularly from the Silicon Valley, started their business and R&D activities in Taiwan (Lin, 2009). The spillover of know-how from ITRI and the Silicon Valley led to a constant increase in the number of patents registered with the USPTO since 1985 (see Figure 4). The recession of the US economy in 2000 and the conducive environment in Taiwan for science and technology development had spurred

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13 The establishment of TSMC had induced many returnees from abroad to start up their own Integrated Circuit (IC) design house and other high technology companies in Hsinchu Science Park of Taiwan (Lin, 2009).
Taiwanese abroad to return home and they contributed towards building the knowledge-based economy. In addition, the reduction of government involvement to allow the private sector to lead science and technology development in 1993 brought about a subsequent boom in 2000.

The total number of utility patents granted for Taiwan is 64291 for the period of 1963 to 2007. The patent owners who acted as the agents of innovation are individuals (the SMIs) who had the interest in exploiting the commercial values of new technology in the US market. The data showed that most of the patents were of local origin.

For the case of Taiwan, the semiconductor device manufacturing, electrical connectors and active solid-state devices were the three prominent fields of technology that recorded an increasing number of patents registered with USPTO (see Figure 10). Electrical system devices and illumination were among the emerging technologies for Taiwan.

![Figure 10: Total Number of US Utility Patents of Taiwan by Field of Technology.](image)

The role of universities in Taiwan evolved similarly like South Korea, from teaching and conducting basic research to supporting industrial technologies and commercializing their research outputs for the market (Choung and Hwang, 2000). Applied physics, condensed matters science, material science and engineering, and, electrical and electronics engineering were the three main fields\(^\text{14}\) that recorded an increasing number of papers in the ISI database, and the related research activities of the universities supported the development of Taiwan industrial technologies (Figure 11).

The government efforts in the early stage of science and technology development and the active role played by the private sector in development since 1993 led to constant increases in the number of patents registered with USPTO. The Taiwanese research institutions and firms

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\(^{14}\) These fields were heavily funded by the government.
excelled in consumer electronics, semiconductors, and telecommunication equipment, and their achievement was comparable to that of Japan. The government efforts in building the technological capabilities of Taiwanese research institutions contributed to significant production of patents over the years, which outperformed some established research institutions in Japan and other NIEs (see Table 3).

As is the case of South Korea, Taiwanese trends of knowledge stock suggest emerging potential of diffusion in science and technology (see Figure 8 and Figure 9), corresponding to the findings of Hu and Mathews (2005). Its AC is likely to increase in response to the increased stock of science and technology. In addition, the diverging level of technological stock between Taiwan and South Korea (although not highly marked) pointed higher level of knowledge stock achieved by Taiwanese innovation system.

4.3 Singapore

Singapore adopted a strategy that emphasized government facilitation of multinational corporations (MNCs)-induced technological learning (Koh and Wong, 2005). The Singapore science and technology policy supported the MNCs that aimed to upgrade their manufacturing process capabilities to manufacture new and advanced science and technological products in Singapore. Thus, the local assembly firms that were awarded contracts by the MNCs might also benefit in the process. The industrial technology grew from simple manufacturing operations in the 1970s to high value-added products and manufacturing activities, and science-based technological R&D activities accelerated since the early 1990s. The production of science and technology was becoming essential for growth. A total of 3698 utility patents were granted to
Singapore for the period of 1963 to 2007 (USPTO, 2008). Local large firms, small and medium enterprises, universities and research institutions dominated the share of the patents of Singapore in USPTO. They started to venture in commercial exploitation of new technologies in the US market since the early 1990s.

Unlike the case of South Korea and Taiwan in which firms and industries played an important role as technology producer of the country, Singapore universities, particularly National University of Singapore had been actively commercializing research outputs with high-technology spin-off (see Figure 12). The fields with increasing number of patents registered with USPTO were semiconductor device manufacturing and active solid-state devices. Dynamic magnetic information storage and retrieval and electricity measuring and testing were among the areas of emerging technology for Singapore (see Figure 13).

![Figure 12: Total Number of US Utility Patents of Singapore by Organization.](image)

Applied physics, condensed matters and materials science, material science and engineering, electrical and electronics engineering, mechanical engineering, chemical physics and AI, robotics and automation control were the prominent fields in the universities that recorded increasing number of publications in the ISI database for Singapore (Figure 14). The research activities supported the development of the technology of the country’s industrial process. The commitment to develop a range of technologies including those for semiconductor, material processing, organic fine chemistry, chemical technology, electrical energy, biotechnology and audio-visual technology was visible.

The technological production, as proxied by the number of patents, of Singapore research institutions (including universities) is comparable to that of South Korea and Japan (see Table 3). The conducive environment for science and technology development in Singapore attracted global talents to participate in and contribute to its growing and dynamic knowledge-based
economy. However, due to the nature of economic structure\textsuperscript{15} and technological capabilities\textsuperscript{16} of Singapore, the local firms and their technological specialization in consumer electronics, semiconductors, and telecommunication equipment were incomparable to that of South Korea, Taiwan and Japan. The growth of patenting activity from Singapore owned firms or industries was relatively weak compared to the achievement of firms owned by Taiwanese or Japanese. The inertia of MNCs-focused export-oriented economy of Singapore built over the years limits them to leap-frog into an entrepreneurial-knowledge based economy.

![Figure 13: Total Number of Patents of Singapore by Fields of Technology.](image)

From Figure 8 and Figure 9, it can be observed that generation of Singaporean knowledge stock in science and technology is relatively lower compared to South Korea and Taiwan, suggesting a gap to be caught up. Apart from that, trends of knowledge stock of Singapore imply emerging potential of diffusion in science and technology.

\textsuperscript{15} Science and technology policy was used to attract FDI for economic growth.

\textsuperscript{16} Capability in processing technologies that supported the MNCs had advanced the manufacturing activities in Singapore.
Since the reform of the economy in 1978, China experienced significant economic development and rapid industrialization. The manufacturing export orientation policy was adopted as the strategy for growth. The policy led to relocation of labour-intensive assembling processes of leading international textile, garment, electric and electronics multinationals to the Chinese export processing zones. However, China achieved only modest technology development due to the lack of concerted efforts in the promotion of R&D activities, lack of skilled labours and engineers, and poor infrastructure for R&D activities.

The government anticipated that the economic growth of China that depended on the FDI which mainly took advantage of the availability of low labour costs may not be sustainable for long-term development, especially in the face of pressure of currency appreciation over time. Systematic reform of Chinese innovation system began since the mid of 1980s. Since then, China witnessed reforms in their institutional structure to advance their horizontal linkages among national research institutions, universities and industries (Xue, 1997, Motohashi and Yun, 2007, Hu and Mathews, 2008, and Zhao et al., 2009). To move to high value-added technological production, the science and technology policy was developed to encourage upgrading of manufacturing process capabilities for the manufacturing of new and advanced products by the MNCs. Many industrial cluster science parks, high-technology infrastructures and research institutions were established to provide industries with the necessary support and such efforts successfully induced industrial technological innovation. Many Chinese firms that support the operation of MNCs in China benefited from the spillover effects and moved away from cheap-

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Figure 14: Total Number of ISI Papers of Singapore by Fields of Science.

4.4 China

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\textsuperscript{17} Chinese government has gradually reduced their funding to research institutions’ operational costs, pushing them to acquire resources from industries (Xue, 1997).
labour manufacturing activities since the mid of 1990s. Many local firms were moving forward to higher value-added products and processes and they were highly involved in applied R&D activities. The change witnessed a surge in the number of patents produced (see Figure 15).

The total number of utility patents granted to China was 3650 for the period of 1963 to 2007. The local firms, particularly small and medium enterprises, and universities dominated a large share of the Chinese patents registered with USPTO. Hon Hai and Huawei Precision Engineering Firms were among the notable applicants for patents with USPTO. These firms developed high precision engineering and automated machinery manufacturing capabilities since links were established with the export-oriented manufacturing semiconductor firms (MNCs) in China. The development was associated with the demand of high precision machine tools by the MNCs.

![Figure 15: US Utility Patents of China, Malaysia and Thailand](image)

Electrical devices (such as electrical connectors and systems) and material sciences and engineering (such as natural rubbers) were among the prominent fields of technology that had increasing number of patents (see Figure 16). Drug, body treating composition and biotechnology (such as molecular biology and microbiology) were among the emerging technologies for China. The emerging trends of these technologies, seen as innovations for the next global technological waves, implied the commitment to build knowledge specialization and competency to reinforce the future development of their biotechnology and nanotechnology industries.

Although China had high commitment of resources for science and technology institutions during this catching-up process, the change in technology innovation performance had been recent. Its development and production of technology remained behind of those of the NIEs and Japan.

China followed the nanotechnology initiatives of the US since 2000 and raised scientific outputs successfully. Applied physics, condensed matters and materials science, physics, and, material science and engineering were among the scientific research areas in the Chinese
Figure 16: Total Number of US Utility Patents of China by Fields of Technology.

Figure 17: Total Number of ISI Papers of China by Fields of Science.

semiconductor technology (see Figure 17). China became one of the leading nations in terms of scientific research output due to the combination of huge supply of engineers and R&D
universities that thrived in response to development of the next technological wave in scientists, basic R&D investment and the return of qualified Chinese scientists from abroad. However, many research publications from the Chinese scientists had low citation impact (Wu et al. 2004 and Guan and Ma, 2007) and low correlation with the patents production in USPTO. This suggests mismatch of scientific development with the current progress of technology of China despite their strong basic research efforts.

Apart from the fact that the growth Chinese economy remained depended on the availability of low labour costs, the knowledge stock of papers and patents imply significant capacity to assimilate, utilize and diffuse its science and technology in the economy (see Figure 8 and Figure 9). The diverging of scientific knowledge stock between China and the NIEs marked higher level of productivity attained by China. The technological stock attained by China was comparable with that of the NIEs. This could be attributed to huge supply of engineers and R&D scientists in contributing to the growth of its knowledge-based economic development.

4.5 Malaysia

Development policies in Malaysia experienced a significant change since the introduction of development plans in the 1960s. Jomo and Felker (1999), Hobday, (1999), and Rasiah (2001 and 2002) analyzed the changes from the 1960s to 1990s. The structure from an economy dependent on agriculture and primary commodities to a manufacturing based and export driven economy. Rapid industrialization was recorded since.

The government began to emphasize science and technology development from 1986 when the first Industrial Master Plan (IMP) was launched. The impressive economic growth during the 1990s and the IMP impacted the science and technology activities positively (Asgari and Wong, 2007). The total number of patents registered with USPTO advanced significantly since 1995 (see Figure 15). The evidence shows Malaysia’s potential for attracting applied research activities from the MNCs. The MNCs took advantage of the local resources, both in terms of local talents and infrastructures, to build their capabilities and appropriated these patents for their technological gain. The inability of local firms to shift activities to the higher value-added activities and R&D because of scarce supply of engineers and R&D scientists, poor quality of some local graduates, low R&D investment and the reluctance of most qualified Malaysians to return home from foreign sites made it difficult for local firms to benefit from the activities (Rasiah and Wong, 2009).

The total utility patents granted for Malaysia is 795 for the period of 1963 to 2007 (USPTO, 2008). Small and medium industries have strong presence in the patenting activities in USPTO. However, the technological capabilities and development were dependent on FDI. Closer examination of the data shows that most patents belong to the MNCs of American and Singapore origin. These foreign assigned MNCs’ patents comprised the major share of the total number of Malaysian patents. MNCs like Motorola, Intel, Agilent, Avago and Chartered Semiconductor have strong presence in Malaysia’s electronics and semiconductor firms. In fact, the MNCs of South Korea and Taiwan showed an increasing patenting trend over the years due to their increasing presence in Malaysian manufacturing activities. Due to the reliance on foreign technologies for development, the production of patents is incomparable to that of NIEs. In addition, the inability of existing firms to shift towards higher value added activities has compounded the problem of slow growth in the number of patents produced.
Due to the nature of manufacturing activities and technological competencies of the MNCs in Malaysia, semiconductor device manufacturing and active solid-state devices were the two prominent fields of technology that had increasing numbers in the patents awarded by USPTO. Emerging trends were visible in areas such as radiant energy and illumination (see Figure 18).

![Figure 18: Total Number of US Utility Patents of Malaysia by Fields of Technology.](image)

The combination of R&D incentives and subsidies from the government that stimulated interests in scientific publication and better infrastructural support had advanced the production of scientific papers. Physical chemistry, material science and engineering, and applied physics, condensed matters and materials science, were among the scientific research activities that were highly funded by the government, in the hope for universities to support industrial technology development and produce knowledge for catching up with the global technological waves. Emerging trends in biomedicine and biotechnology such as pharmacology, food science and nutrition and toxicology and microbiology in basic research activities were also quite visible (see Figure 19). However, the production of papers is incomparable to that of the NIEs. In the 1980s and early 1990s, Malaysia and the NIEs were identical in the production of scientific knowledge in the region of South East Asia. However, since then, the NIEs outperformed Malaysia in terms of science production and the gap is expected to widen if there is no progress in Malaysia’s innovation system (Wong et al. 2010).

In addition, many research publications had low correlation with the patents production in USPTO. The spillover effects were somewhat poor. Although there were positive signs of growth in science and technological capabilities (measured by papers and patents), innovation and patent production was still quite small and the growth of learning capabilities was weak (MOSTI, 2006). The total number of papers and patents of Malaysia is not only significantly behind the NIEs over the past decades, but the systemic problems could create a barrier in furthering the development of science and technology.
The plots in Figure 8 and Figure 9 suggest gradual increase in Malaysian assimilation capacity of science and technology. However, its knowledge stock was incomparable with the NIEs and China.

4.6 Thailand

Thailand attempted to build its economy on developing and producing higher value-added products since the 1990s. The growth of Thai economy recorded positive effects on its technological activities and development since the mid of 1990s (see Figure 5). However, the trend of technological development shrunk since the struck of the world electronic slump in 2001. Thailand is the only country in this analysis that did not experience an increasing trend in the number of patents produced since the turn of the millennium. In addition, many MNCs relocated their operations and technological activities from Thailand to China due to lower labor costs and the recent advancement of Chinese science and technology capabilities (Altenburg, 2006).

The total number of utility patents for Thailand is 281 for the period of 1963 to 2007 (USPTO, 2008), which is the smallest among the selected countries. Small and medium industries and the American MNCs had the major share of the total number of patents. Advanced Micro Devices (AMD) of America alone had a share of 21 percent of the total. Drugs and bio-affecting composition, semiconductor device manufacturing and active solid-state devices were those that recorded high number of patents (see Figure 20).

The combination of R&D incentives and subsidies from the government and science and technology infrastructures made Thailand prominent in the production of scientific papers in South East Asia. However, like the case of Malaysia, the policy based on the linear model of innovation approach failed to create linkages among institutions (Intarakumnerd, 2006). In addition, the fields of science that were highly funded by the Thai government showed mismatch
and were of little help to the electrical and electronics industrial technological development. The scientific knowledge built over the years showed the commitment of the government to develop the pharmaceutical and cosmetic technology (see Figure 21). Efforts to develop science to support electrical and electronics and semiconductors technology were somehow neglected, despite the potentials witnessed in the growth of patents.

**Figure 20:** Total Number of US Utility Patents of Thailand by Fields of Technology.

**Figure 21:** Total Number of ISI Papers of Thailand by Fields of Science.
As is the case of Malaysia, the plots in Figure 8 and Figure 9 suggest gradual increase in Thai assimilation capacity of science and technology in corresponding to the increased of knowledge stock. On the other hand, its knowledge stock is relatively lower compared to the NIEs and China, suggesting a gap to be caught up.

6. Conclusion

While Wong and Goh (2009) suggested a model that stressed on systemic and cumulative aspects of knowledge18, this paper highlights the pathways taken by the selected countries to achieve development and how the distinctive national innovation systems contributed to growth and productivity in science and technology. The findings revealed the efforts of Asian countries in developing their innovation system. The study demonstrated the institutional dynamics that drive the self-propagating functionality behaviour, thus offering a more complete theoretical understanding of the innovation systems of selected economies in Asia than those studied by Choung and Hwang (2000) and Bernadas and Albuquerque (2003).19

The empirical analysis suggested that a well developed national innovation system is vital for development of self-propagating behavior that promotes the growth of science and technology. This virtuous cycle is built based on synergies and systemic effects. The scale and volume of knowledge stock, persistency of knowledge investment and production as results of the systemic effects explained the mechanism of self-propagating behaviour.

Based on the analysis in this study, Table 5 summarizes some generic dimension of current development and commitment in developing self-propagating behaviour for growth in a knowledge-based economy. Figure 22 illustrates the environment and the interaction process. The NIEs namely South Korea, Taiwan and Singapore recorded significant progress in the accumulation of knowledge in science and technology that led to self-propagating behaviour in the evolution of its growth. The science and technology policy of South Korea and Taiwan designed to avoid over-reliant on the technologies of MNCs during the early stage of industrialization had provided an alternative route for the nation to learn and acquire technologies through mechanisms other than FDI. The strategy was effective in acquiring science and technological capabilities, and the economies succeeded in catching-up and moving towards the world production frontier. The entrepreneurial university model of Singapore was effective in attracting foreign talents to contribute to the growth of knowledge economy. Among the strategies adopted by the NIEs, the chaebol conglomerate of South Korea and the techno-entrepreneurial formation in the Hsinhu-Taiwanese model led to promising development in the potential and vitality of science and technology. The trends and trajectories were comparable with those of advanced countries like Japan, and provided policy lesson for the other developing economies.

China’s sustained growth of science and technology was impressive due to the combination of huge supply of engineers and R&D scientists, basic infrastructures and the return

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18 Knowledge is recognized as complementary assets and the central features for the development of science and technology in the Asian countries covered in this study.

19 Without considering the stocks and trends of science and technology, these studies focused on the count of papers and patents could limit a comprehensive understanding of Asian innovation system.
Table 5: Classification According to Reinert's Index of Economic Activities

<table>
<thead>
<tr>
<th>Science and Technological Innovation</th>
<th>Characteristics</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Quality Activities</td>
<td>1. New Knowledge with high market value</td>
<td>Japan, South Korea, Taiwan, and Singapore</td>
</tr>
<tr>
<td></td>
<td>2. Science and technology progress</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. High R&amp;D content</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Linkages and Synergies</td>
<td></td>
</tr>
<tr>
<td>Low-Quality Activities</td>
<td>1. Knowledge with old market value (FDI)</td>
<td>China, Malaysia and Thailand</td>
</tr>
<tr>
<td></td>
<td>2. Little science and technology progress</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Low R&amp;D progress</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Produce few linkages and synergies</td>
<td></td>
</tr>
</tbody>
</table>


Figure 22: Interactive Learning and Searching Model

of qualified Chinese scientists from abroad. Furthermore, many local firms were aggressively moving-up the technological value-chain in the transition from labour intensive to knowledge-
based economy and catching-up with the world technological frontier. On the other hand, China’s reliance on FDI for growth and technology development and some mismatch of science and technological development could hamper the growth process.

Thailand shared similarities in the catch-up pattern with Malaysia, with both relying on FDI for growth, with the risk of falling behind due to the limited self-propagating behaviour in science and technology. The accumulation of science and technology stock was not sufficient to develop the self-propagating behaviour. Their science and technology policy had achieved limited success in moving up the science and technological value-chain and creating innovation rents to shield them from the competition in price and cheap labour cost. Although science witnessed growth over the decades, the knowledge cannot be fully exploited in the national innovation system, thereby hindering speedy progress within the technological realm that is imperative for growth. Strengthening the innovation system which contributes to science and technological knowledge is essential to succeed in the catching-up process.

References:


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APPENDIX 1

Disciplines in Science and Concordance for Technology Classification

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Science Areas</th>
<th>Technology Areas</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecommunications</td>
<td>Communications engineering</td>
<td>Telecommunications</td>
<td>NIEs and Developing Economies</td>
</tr>
<tr>
<td>Informatics</td>
<td>Computer science, applied mathematics</td>
<td>Information technology</td>
<td>NIEs and Developing Economies</td>
</tr>
<tr>
<td>Electricity</td>
<td>Electrical engineering, electronics</td>
<td>Electrical machinery and apparatus, electrical energy</td>
<td>NIEs and Developing Economies</td>
</tr>
<tr>
<td>Measurement</td>
<td>Instrumentations, applied physics, statistics</td>
<td>Analysis, measurement, control technology</td>
<td>NIEs and Developing Economies</td>
</tr>
<tr>
<td>Biomedicine</td>
<td>Allergy, cancer, cardiovascular system, metabolism, general and internal medicine, immunology, pathology, pharmacology, toxicology, etc</td>
<td>Pharmaceutics and Cosmetics</td>
<td>Korea, Taiwan, Malaysia, and Thailand</td>
</tr>
<tr>
<td>Biotechnology</td>
<td>Biochemistry, Molecular biology, microbiology</td>
<td>Biotechnology</td>
<td>NIEs and Developing Economies</td>
</tr>
<tr>
<td>Organic Chemistry</td>
<td>Organic Chemistry</td>
<td>Organic Fine Chemistry</td>
<td>NIEs and Developing Economies</td>
</tr>
<tr>
<td>Inorganic chemistry</td>
<td>Applied, physical inorganic chemistry, chemical engineering</td>
<td>Chemical and petrol technology, basic materials chemistry and chemical processing</td>
<td>NIEs and China</td>
</tr>
<tr>
<td>Materials</td>
<td>Material Science, ceramic materials, metallurgy, molecular and chemical physics</td>
<td>Surface technology, coating, textile, papers</td>
<td>NIEs and Developing Economies</td>
</tr>
</tbody>
</table>

Adapted from Grupp (1998, pp. 168-170).