Catch-up Industrialization and Growth Trajectory of Science and Technology: A Comparative Study on Asian Economies

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Abstract

As typical emerging economies in the race for acquiring innovation rents, many emerging economies have the urgency to transform their economy in which dependent on export-oriented manufacturing to knowledge-based economy. Many studies highlighted the pathways taken by these economies to achieve development and how distinctive national innovation system contributed to growth and productivity in science and technology. Through theoretical analysis and empirical demonstration, this paper attempts to capture in a stylized the national innovation system strategies in shaping science and technology trajectories for South Korea, Taiwan, Singapore, Malaysia and China. The science and technology (proxied by papers and patents) trajectories were examined using bi-logistic growth function. The findings suggests that catch-up governing strategic model of South Korea and Taiwan had led to much longer and higher development trajectories during the transition towards knowledge-based economy than countries that are dependent on FDI for learning and acquiring technology such as Singapore and Malaysia.

Keywords: Catch-up Industrialization Models, Growth Trajectories, Science and Technology, Papers and Patents, Asian Economies

1. Introduction

The newly industrialized economies (NIEs) and the emerging economies of Asia have been growing fast and strong, even after experiencing several economic crises over the decades (Keller and Samuels, 2003). South Korea, Singapore, and Taiwan, as the newly industrialized economies, are notable for maintaining high growth and rapid industrialization. They have achieved remarkable rapid industrial and science and technological catch-up (Wong, 1999). Their science and technology policies have successfully advanced the basic and applied research-based activities that led to a development pattern that is consistent with self-propagating growth in science and technology (Wong and Goh, 2009). Developing countries of Asia, such as China and Malaysia emerged as fast-growing economies given their strong export performance and the availability of cheap and semi-skilled labour. In the transition to a developed and knowledge-based economy, these countries placed emphasis on upstream activities, attempted to raise
national investments in R&D and researchers since the 1990s to develop its science and technological capabilities.

As typical emerging industrializing economies in the race for acquiring innovation rents, South Korea, Taiwan, Singapore, China and Malaysia have the urgency to transform their economy in which dependent on export-oriented manufacturing to knowledge-based economy. Many studies highlighted the pathways taken by these economies to achieve development and how distinctive national innovation system contributed to growth and productivity in science and technology (Fagerberg and Godinho, 2004, Hu and Mathews, 2008, and Tseng, 2009). These late industrializing economies have been engaging in standard-related activities, building manufacturing capabilities and focusing on import substitution of parts and components (Amsden and Tschang, 2003). As their production moves up the value chain (from being merely standard followers to standard leaders), these economies stepped up investment in applied research to improve their technological capability (Ratanawaraha, 2005). A few countries of Asia begun to catch-up with the advances economies, largely attributed to their well functioning national innovation system (Mazzoleni and Nelson, 2003, Wong and Goh, 2009 and 2010a). The strategic model of national innovation system of these economies led to promising development in the potential and vitality of science and technology, provided policy lessons for the other developing economies.

The evolving models of science and technology policies led to divergent trajectories of science and technology growth and diffusion. Wong (1999), Wong and Ho (2007) and Wong and Goh (2010b) suggest the generic technological capability development routes in two distinctive models:

- **New Start-ups for Product Technology Pioneering Model:** The model generally involves government incentives and supports to fuel entrepreneurial activities, reduce risks by firms that involved in costly investment for innovation, and stimulate R&D investment for science and technology. Advanced entrepreneurial infrastructure is central for development. Technology policy is basically designed to avoid over-reliant on MNCs’ technologies during early industrialization. State intervention practice is essential to build technology capabilities and competencies, particularly during the infant stage of industrial development (Nelson, 1993, Alavi, 1999 and Reinert, 2008).

- **FDI Leveraging Model- Technology policy is developed to favor the MNCs (Multinational Corporations) that wish to upgrade their manufacturing process capabilities to manufacture new and advanced products. The spillover of know-how from the multinationals would spawn many local supporting industries and lead to constantly increase of technology among local linkages firms. This could be done so by focusing on the provision of basic infrastructure, political stability and security to support export-intensive manufacturing activities.

Industrial policy\(^1\) of late industrializing economies like South Korea and Taiwan have traditionally placed emphasis on entrepreneurial infrastructure and development of local-owned

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\(^1\) We follow the definition of Chang (2003, pg. 113) where industrial policy is defined as “a policy that intended to affect particular industries to achieve outcomes that are perceived by the state to be efficient for the economy as a whole”. “The policy attempts to change the economic structure over and beyond what the market is able to do by inducing the private sector agents into new activities that they do not have interest in entering under free market conditions.”
manufacturing industries, while FDI leveraging countries like Singapore and Malaysia have traditionally emphasized on institutions that facilitates the operation of MNCs and spillover of technology between the MNCs and its local subsidiaries firms. In search for workable policies for science and technology, China has been maintaining two competing models operated at the local (or regional) level² toward science and technology development. The success of one region in science and technology provides some guides and policy implications to other regions to adopt similar policies and model for development. The policies run in regions may eventually be elevated to central policies for development of national science and technology (Naughton and Segal, 2003).

In the transition to knowledge-based economy, science and technological stock emerged to be significant. Both models generally witnessed positive effects on science and technological knowledge stock and development in many Asian emerging countries since the 1990s (Wong and Goh, 2010b). Commitments and initiatives to improve competitiveness appear to be in place in these emerging countries, it remains to be observed to what degree of successful development of their technological innovation.

To date, although many studies have been conducted to examine the extent of science and technological growth and development in many Asian emerging countries, a systematic approach to examine the diverging growth trajectories of science and technology is still severely lacking in the literature. The focus of the preceding diffusion and development studies (Bhattacharya, 2004, Hu and Mathews, 2005, Leydesdorff and Zhou, 2005, Zhou and Leydesdorff, 2006, and Wong and Goh, 2010a,c) without considering the models of science and technology policies and structural change of economic activities limits a comprehensive understanding of Asian science and technology growth in knowledge-based economic development. By the mean of theoretical analysis³ and empirical demonstration, this study aims to trace the science and technology (proxied by papers and patents respectively) growth trajectories based on bi-logistic growth function considering the structural change in economics activities from industrial-based to a knowledge-led development. The study provides a comparative analysis on selected NIEs and fast-growing economies in Asia. South Korea, Taiwan, Singapore, Malaysia and China are included in this study for their different level of achievement in development and adoption of different models for science and technology development.

There are significant commonalities between the selected economies to warrant some arguments and discussion of Asian innovation system. These economies are compared in this study for several reasons. The science and technology development path of these economies had many similarities in their evolution trajectories, technological option and avenue of innovation⁴ (Hobday et al., 2001, Archibugi and Pietrobelli, 2003, Fagerberg et al., 2007, Tseng, 2009 and Wong and Goh, 2010b). Their science and technology policy evolved from solely supporting situation” (Chang, 2003, pg. 313). State-own enterprises or government linked companies in these economies were established to facilitate their economic development in specific sectors (sectors in which required huge capital investment and protection such as transportations, utilities and automobile industries).

² The improvised strategy is viable due to the size and diversity of the country (see Naughton and Segal, 2003).
³ This study seeks to integrate insights from institutional theory and innovation studies to provide a coherent view on the national institutional dynamics that drive the development of science and technology.
⁴ The use of information and communication technologies (ICT) is particularly essential for economic growth in these economies.
technological development in manufacturing industries to strengthening the role of national science and technology institutions to support transformation towards a knowledge-based economy. It would therefore be interesting to compare the extent of divergence in science and technological growth trajectories of these economies.

2. Concept and Methodology

The aim of this section is to lay out a conceptual model describing the contexts for catching-up strategies and a taxonomy of bi-logistic growth function explaining growth trajectories of science and technology.

2.1 Elucidation of Catching-up Industrialization Strategies

The order of discussion proceeds from the case of new start-ups for product technology pioneering model to FDI leveraging model.

Basically, there are two dominant catch-up governing strategies for new start-ups for product technology pioneering model adopted by many developing economies to learn and acquire technologies through mechanisms other than FDI.

- Chaebol conglomerate approach
- SMI-state network approach

For the case of South Korea and Taiwan, the strategies were effective in acquiring many technology capabilities (particularly in ICs and semiconductor), and their economies succeeded in catching-up and moving towards the world production frontier. This virtuous cycle is built based on synergies and systemic effects.

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 of the local firms during the 1960s. The firms of South Korea adopted the reverse product life cycle strategy to develop their technology capability. The strategy involved is to first develop the process capability, then followed by developing sophisticated products through imitative R&D. Finally, firms invest in R&D for own product and process technologies (Wong, 1999).

To move up the value-chain of technology, South Korea practice 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 a 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).

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5 The magnitude of knowledge spillover to the local economies was impressive due to the adoption of the mentioned strategies to develop high technological sectors.
1999, Lee, 2006 and Rasiah, 2007). Their dynamic technology policy led to systemic learning and catching-up with the advanced technology of developed countries in most chaebol firms, which subsequently led to growing technological capabilities (Lee and Lim, 2001, Yun, 2007, and Joo and Lee, 2009).

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 is to first develop the process capability through the mastering of contract assembly operations (Original Equipment Manufacturing, OEM), then followed by developing sophisticated products through imitative R&D. Finally firms invest in R&D for own product and process technologies (Original Design Manufacturing, ODM). According to Jan and Chen (2006), the R&D system of Taiwan consist of industrial firms, government supported institutions and universities. Most of the Taiwanese firms are small. Therefore the R&D resources for developing new technology are limited. In addition, large firms in Taiwan spent little on R&D activities and the firms were dependent on their foreign partners (the MNCs) to develop new technology. The government supported institutions, including the Industrial Technology Research Institute (ITRI) established in 1973, are to support the technology development of small and medium industries (SMIs) of Taiwan. ITRI plays an important role in initiating, developing and supporting industrial R&D activities. ITRI have set up laboratories with firms with the purpose of improving quality and manufacturing processes of products. Many firms (such as UMC and TSMC) have successfully spun-off from technology acquired from the ITRI laboratories (Hu and Mathews, 2005). Many Taiwanese firms now attempt to develop their own products that are sold under their own brands (Original Brand Manufacturing, OBM). All these activities are strongly supported by the ITRI laboratories and development schemes. Taiwanese firms gradually move to higher value-added products and involved in themselves science-based technological R&D activities. Accordingly, many academic researchers increased their involvement in R&D activities for industrial firms. Interaction between firms, government support research institutions and universities is central for development in which activities between science, technology and market initiate, import, use, modify and diffuse science and technology.

The role of the Taiwan government changed from investment and facilitation to the role of triggering R&D activities during 1970s to stimulate learning and innovations in SMIs. The Taiwanese SMIs transformed their simple manufacturing operations to higher value-added ODM activities and OBM. According to Rasiah and Lin (2005), the integrated operations of market, government and social trust had reduced government failure in R&D investment to help raise the flow of reliable information and performance-oriented commitment.

Singapore, Malaysia and China (the province of Guangdong in particular) adopted a strategy that emphasized government facilitation of multinational corporations (MNCs)-induced technological learning (Koh and Wong, 2005). Their 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

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6 The activities include telecommunication engineering, biomedical, IC design, optoelectronics and material science.

7 During the 1970s and 1980s, the interaction between universities and industrial firms is limited.
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. In the early 1990s, the government of Singapore and Malaysia started to increase their investment in basic research activities to pursue application pioneering strategy. This strategy accelerated the development of technological capabilities among the MNCs and local firms through the adoption of new and advanced technologies in their manufacturing processes. There are many studies suggest that Singapore and Malaysia has the potential for attracting applied research activities from MNCs (see Amsden and Tschang, 2003 and Chandran and Wong, 2010). The MNCs have taken the advantage of the local resources (in term of local talents and infrastructures) to build their capacity andappropriate the collective knowledge embodied in organizational routines and institutional memory for their economic and technological gain.

2.2 Taxonomy of Bi-logistic Growth Function

In an innovation system, universities and research institutions (the national science system) are the core producers of science output (knowledge production and transfer) while industries (the national technological system) are the core producers of technology output (Lundvall, 1992). We believe the extents of functions of an innovation system are managed and policies and institutions are adopted through conscious and collective with bounded rationality choices. Therefore, due to the unique national innovation system, and co-ordinated strategies and efforts for science and technology, a nation would have distinctive characteristics in the development process. It is important to study the production of science and technology as output of the national innovation system.

Research on science and technology production in the literature explains how science and technological innovation spreads among adopters through the form or pattern of the S-curve (Daim et al., 2006). Following Kondratieff-Schumpeterian business life cycle theory, there are many functions used as analytical approach to capture the life cycle of science and technology and explain the phenomena or test specific growth hypothesis (Baudish and Grupp, 2006). The simple logistic function stated below is of the most common form:

\[
p_t = \frac{K}{1 + ae^{-bt}}
\]

where:
- \( p_t \): value of the unit of science/technology at time \( t \),
- \( K \): potential limit of growth or carrying capacity
- \( a \): initial stage of growth
- \( b \): velocity

To plot the S-curve on log-linear function,
The logistic growth function has a carrying capacity $K$ that is constant, with the base given by coefficient $a$. The carrying capacity provides an indication to the underlying potential of the process. A constant carrying capacity of the logistic growth function implies that the limit to potential of science or technological production is fixed at some given level.

The simple logistic function that has its origin in the biological realm is often used to model the production of science and technology due to its rich empirical description and its effectiveness in capturing the changing nature of science and technology (Devezas et al., 2005). The epidemiological concept is used to describe the spread or production of science and technology. The production of science and technology is basically influenced by internal sources, a process through contacts among agents of the social and innovation system. Many studies (Gupta et al., 1997, Anderson, 1999, Teng et al., 2002, Watanabe et al., 2003, Bengisu and Nekhili, 2005, Devezas et al., 2005, and Nagamatsu et al., 2006) demonstrated that the external influence is relatively weak (revealed through extremely low coefficients and poor fit of the internal influence model) compared to internal influence. Many studies which focused on internal influences found this function useful to fit and describe the growth pattern of science and technology (Anderson, 1999, Foster and Wild, 1999, Teng et al., 2002, Bengisu and Nekhili, 2005, Devezas et al., 2005, and Kucharavy and Guio, 2008).

The selected Asian economies are currently evolving from an economy dependent on labours and capitals to economies that dependent on knowledge-based development. The shift is likely to witness an increasing return to production of science and technology. This is attributed to the properties of knowledge that have characteristics akin to increasing returns (Foray, 2006).

Considering the perspective of paradigm shift from industrial to post-industrial knowledge-based economic development, it is crucial to separate the production into two stages of development (before and after knowledge-based economic development) to capture the two impulses of growth. Given two serial paradigm processes, each paradigm is modeled with a simple logistic function. By this, the persistence and ability to improve the production of science and technology (the growth characteristics) in the process of paradigm shift can be observed from the acceleration of the emergence of the second waves. The following equation depicts two combined simple logistic growth functions.

\[ L = p_t (1 + ae^{-bt}) \]
\[ \frac{L}{p_t} - 1 = ae^{-bt} \]
\[ \log\left(\frac{L}{p_t} - 1\right) = \log a + bt \]
\[ p(t) = \frac{K_1}{1 + a_1 e^{-b_1 t}} + \frac{K_2}{1 + a_2 e^{-b_2 t}} \]  \hspace{1cm} (3)

where:

- \( K_1 \) and \( K_2 \) are the carrying capacity for the first and second waves respectively.
- \( a_1 \) and \( b_1 \) are coefficients for the first logistic function
- \( a_2 \) and \( b_2 \) are coefficients for the second logistic function

A spectrum of curves can be generated from Equation 3. We follow the Meyer’s taxonomy of curves (see Meyer, 1994) as a reference to analyze the systems of production of science and technology. Figure 1 shows the four basic patterns of growth curves in bi-logistic function.

![Figure 1: Taxonomy of the Bi-logistic Growth Function](source: Meyer (1994).)
Following explains some characteristics of the linearized logistic growth curve shown in Figure 1:

- Sequential logistic occurs when the second logistic curve starts once the first logistic curve reaches almost the saturation
- Superposed logistic occurs when the second logistic curve starts to emerge when the first reaches about 20-50 percent of saturation
- Converging logistic occurs when both logistic curves emerge at different period of time and culminate at about the same saturation
- Diverging logistic occurs when both logistic curves emerge at about the same time but grow at different rates with different level of carrying capacity

2.3 Data Source

Scientific resources and production play an important role in technological and knowledge-based economic development (Schmoch, 1997). The term science is often defined as “the creation, discovery, verification, collation, reorganization and diffusion of knowledge about physical, biological/natural and social nature” (Kline and Rosenberg 1986, pp. 287). The term technology is defined as an instrument of adaptation that includes the manufactured hardware or artifacts, skill and knowledge required to design, manufacture and use technology hardware and different forms of organization. Forms of organization include institutional settings and rules for the generation of knowledge and for the use of technologies (Grupp, 1994, and Dosi et al., 2006). Technology can also refer to a collection of techniques.

The term science and technology used in this paper denotes the basic and applied research respectively. Publications are considered specifically as one of the main activities that represents the scientific innovation for the analytical purpose. Publications (papers) that report theoretical works and research findings are the main channel for documentation and dissemination of scientific findings to further the development of science. Patents represent the codified part of technological innovation that reflects the interest in commercial exploitation of a new technology (Kondo, 1990, Grupp, 1994 and Kumaresan and Miyazaki, 1999). According to Schmoch (1997) and Grupp (1998), patents as the most frequently adopted indicator for technology provide measure to inventive and innovative activities that lead to new products or processes in the market.

This paper attempts to elucidate the innovation system of selected Asian economies in shaping the growth trajectories of science and technology using bi-logistic growth function. The data used in this paper are the historical series of ISI publications from 1981 to 2005 (ISI, 2005) and utility patents granted from the US Patent Office and Trademarks (USPTO) from 1984 to 2004 (USPTO, 2005) for selected Asian economies including China, Japan, Taiwan, South Korea, Singapore, Malaysia and Thailand. The ISI database covers world leading journals of science and the US’s patents cover useful information of technological activity. This study assumes that the NIEs and the selected emerging countries in Asia have high tendency to patent scientific and technological knowledge.

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10 Scientific innovation denotes the increases in value of scientific knowledge.
11 Technological innovation denotes the increases in value of technological knowledge.
12 Data for Hong Kong is merged with the data for China.
13 The document provides details of inventive and innovative activities (Bhattacharya, 2004).
their invention/innovation in the USPTO\textsuperscript{14}, as US is the major export market for the selected countries (Bhattacharya, 2004 and Schmoch, 2009). In addition, using US patents data helps to prevent home bias\textsuperscript{15} effect that could be observed in many national patent office (Dachs \textit{et al.}, 2007).

The years covered in this study is useful to reveal the context of two broad trends of development which shape the evolution of innovation system for NIEs and the selected developing countries. The trends are the establishment of science and technology policy for development during 1980s and the continual growth of science and technological production since the 1990s. The ISI publications here refer to all fields of sciences, including natural, physical, health and social sciences. Patents are recorded by grant year that indicates when market access of technologies was secured. The reasons for using these data are their availability, completeness for analysis, and comparability across different countries. The data provide uniform and time robust measures of science and technological innovation, which reflect immediate market and knowledge-based economic development (Hu and Mathews, 2005).

3. Analysis and Results

This section focuses on modeling the growth trajectories of science and technology, using the number of papers and patents as proxy. The bi-logistic growth function (Equation 3) is fitted. The results of the estimated growth trajectories for South Korea and Taiwan are firstly discussed. The subsequent sub-section discusses the results for the FDI leveraging countries, including Singapore, Malaysia and China.

3.1 South Korea and Taiwan

Figure 2 and Figure 3 illustrate the number of papers and patents for South Korea and Taiwan respectively. The figures provide the estimated total production of papers and patents (labeled as estimation), the estimated second logistic curve and the data (labeled as observation). Given the co-existing waves of evolution of papers and patents, the time when each wave emerges can be identified. Each set of growth function models an evolution of a paradigm. South Korea and Taiwan have succeeded in developing new growth avenues over the period examined. In the mid of 1990s witnessed the first logistic wave being over taken by the second logistic wave. These signals hinted a transition from the emergence of science and technology to knowledge-driven activities. The science and technology experienced the paradigm shift from industrial to knowledge-based economy in the early 1990s, which subsequently witnessed the emergence of the second waves of papers and patents production toward the end of 1990s. The persistency of search for new science and technological growth trajectory development would lead to sustainable growth in science and technology.

\textsuperscript{14} Utility patents data from USPTO can be an appropriate indicator for technological innovation (Hu and Mathews, 2005).

\textsuperscript{15} Many inventors apply for their patents at their home patent office. The national internal influence is highly attributed to the competitive environment in the US market. Many Asian firms (local or MNCs) always seek protection for their innovation to compete in the US market.
The papers and patents of South Korea and Taiwan exhibit a diverging bi-logistic growth pattern. The second wave that dwells with significant efforts of knowledge-based economic development shows a longer and higher pulse than the first wave. South Korea and Taiwan regard papers and patents as a unique “capital” to generate value from the intangible assets (the knowledge). Many universities, research institutions and industrial firms (the science and technological systems) of these economies exploited these assets through aggressive application-oriented R&D activities. The trend corresponds to the argument of Foray (2006) that codification of knowledge for the production and reproduction of science and technology is essential for transformation towards a knowledge-based economy. The self-propagating behaviour of science and technology resulted from the significant efforts of the respective government to ensure the successful development of the core sectors (such as biotechnology and information and communication technology) in a knowledge-based economy.

The R&D activities and the successful development of these emerging sectors require learning by searching capabilities and necessary assimilation capacity in their science and technology system in order to benefit from the spillover effects of science and technology. Chaebol firms of South Korea were established to provide avenue for development of indigenous science and technology capabilities. The role of universities public research institutions evolved from training and preparing high of high-quality graduates and conducting basic and applied research for the growth of national productive high-technology enterprises to commercializing their research outputs for the market (Sohn and Kelly, 2007). IPR system of South Korea was established to facilitate administrative procedure and improve the quality and efficiency of patent examination in the USPTO (Lee and Kim, 2010). Such conducive environment and efforts for knowledge-based economic development brought about a rapid increase in the number of papers and patents during the 1990s. The emerged of second wave can be attributed to the agile and cooperative structure of the national innovation system that successfully overcomes the inertia of the old paradigm (undertaking absorptive and adaptive technology development).

For the case of Taiwan, the Industrial Technology Research Institute (ITRI) was established by the government to support the technology development of electrical, electronics and semiconductor SMIs. 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 and Wu et al. 2010). In addition, the reduction of government intervention and involvement to allow the private sector to lead science and technology and market of ICs, electronics and semiconductor in 1993 brought about a subsequent boom in 2000. The self-propagating process dwells in the second wave of Taiwan is driven by a range of collective

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16 The establishment of Taiwan Semiconductor Manufacturing Company (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).
Figure 2: Papers and Patents of South Korea. The inset shows the linearized both of logistic growth curves.
Figure 3: Papers and Patents of Taiwan. The inset shows the linearized both of logistic growth curves.
institutions that encourage investment and risk-taking in high-technology, conducive environment (such as Hsinchu science park) in for science and technology activities and huge supply of engineers and R&D scientists that would creates the demand-pull cycle.

3.2 Singapore, Malaysia and China

Figure 4, 5 and 6 illustrate the case of Singapore, Malaysia and China. The transition from the industrial-based to knowledge-driven activities witnessed the emergence of second waves in the production of papers and patents during the 1990s. The papers of Singapore exhibit a superposed bi-logistic growth pattern. Both curves culminate at about the same saturation. In the early 1990s, the Singapore government started to increase their investment in basic research activities to pursue application pioneering strategy. This strategy accelerated the development of technological capabilities among the MNCs and local firms through the adoption of new and advanced technologies in their manufacturing processes. However, such pursue has not led to much higher pulse in the second logistic curve. The increased of basic research activities on manufacturing processes (to solve immediate manufacturing problems) of MNCs could tended to stray away from triggering self-propagating behaviour between science and technology. The patents of Singapore exhibit a diverging pattern of bi-logistic growth. Both logistic curves emerge at different rates with different level of carrying capacity. The second, larger logistic pulse has a higher and much faster growth time than the first pulse. The experience of Singapore provides an interesting contrast to the cases of South Korea and Taiwan. The Singapore science and technology policy had favoured the MNCs that seek to upgrade their manufacturing process capabilities to manufacture new and advanced products in Singapore (Amsden and Tschang, 2003). However, many MNCs (as the national productive high-technology enterprises) of Singapore may not have the interests of advancing applied research activities. Thus, since the 1990s, universities, research institutions and many selected state-owned enterprises were heavily funded by the state to strengthening the learning capabilities in technology (applied research) and commercialize research outputs with high-technology spin-off. The efforts of advancing applied research activities witnessed significant growth in patents since the 1990s, it remains to be observed to what degree of successful development of their technological innovation for knowledge-based economy.

The papers of Malaysia exhibit a converging bi-logistic growth pattern. Both curves culminate at about the same saturation. Both logistic curves emerge at different period of time and culminate at about the same saturation. The efforts to develop basic research during the transition to knowledge-based economy witnessed a significant increase in papers production. Unlike the case of South Korea and Taiwan, the patents of Malaysia exhibit a diverging pattern of bi-logistic growth. The second logistic pulse has a higher and much faster growth time than the first pulse. The efforts of advancing applied research activities have led to only gradual increase of patents in the second wave of patents. We observe that the basic research activities were lacking in sense of purpose and highly fragmented from the production structure of technology (see Wong et al. 2010). This could be attributed to the rising “bureaucratic barriers” and lacking of “political will” the gradually developed within the technological and institutional foundation of society (see Felker, 2003, Ritchie, 2005 and Gomez, 2009).
Figure 4: Papers and Patents of Singapore. The inset shows the linearized both of logistic growth curves.
Figure 5: Papers and Patents of Malaysia. The inset shows the linearized both of logistic growth curves.
Figure 6: Papers and Patents of China. The inset shows the linearized both of logistic growth curves.
The papers of China exhibit a diverging pattern of bi-logistic growth. Systematic reform of Chinese innovation system began since the mid of 1980s. Since then, China undertook reforms in their institutional structure to advance the horizontal linkages among national research institutions, universities and industries (Xue, 1997, Naughton and Seagal, 2003, Motohashi and Yun, 2007, Hu and Mathews, 2008, and Zhao et al., 2009). The current economic growth of China has recorded positive effects on scientific activities. The combination of huge supply of engineers and R&D scientists and technicians, strong basic R&D investment and the return of qualified Chinese scientists from overseas contributed to the development of a knowledge-based economy, and China had caught up with Singapore and South Korea in the production of science (Leydesdorff and Zhou, 2005 and Zhou and Leydesdorff, 2006). China has become one of the leading nations in terms of research output. The scientific system of China had progressed in an exponential rate (Leydesdorff and Zhou, 2005, and Kostoff et al. 2007). The patents of China exhibit a diverging pattern of bi-logistic growth. The second wave could be dwells with significant supply-push efforts to develop science and technology capabilities shows a much faster pulse than the first wave. 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 and local conglomerate firms. 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. According to Naughton and Seagal (2003), many local private firms are benefited from the spillover effects in these cluster and moved away from cheap-labour manufacturing activities since the mid of 1990s. However, it can be observed that the production of patents for China is relatively lower compared to South Korea and Taiwan, suggesting a gap to be caught-up. It appears that there are untapped potentials of scientific resources (the increase of papers) for technology development due to the nature of manufacturing activities and technological competencies of the MNCs and local firms in China.

4. Conclusion

The findings of this paper have expanded the research on innovation system in characterizing science and technological trajectories in emerging Asian economies. In order to achieve the objectives of research, this study first constructed a conceptual framework to analyze the trajectories of science and technology. The framework of analysis in this study is adopted extensively from the Wong’s theoretical perspective (see Wong, 1999) on national innovation system and Meyer’s taxonomy (see Meyer, 1994) of bi-logistic growth function. Bi-logistic growth function is found useful and effective in highlighting the path of science and technological evolution underlying its catch-up industrialization model. The use of bi-logistic growth function to explain the national innovation system in particular and the changing level of science and technology is a relatively new effort in the literature.

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17 Chinese government has gradually reduced their funding to research institutions’ operational costs, pushing them to acquire resources from industries (Xue, 1997).

18 The inertia of MNCs-focused export-oriented economy built over the years could be a hindering factor for the economy to leap-frog into a knowledge based economy.
For the case of South Korea and Taiwan, the economies that learn and acquire technologies through mechanisms other than FDI, the evidence suggests a sign of transition from industrial-based to knowledge-driven activities and the formation of evolving dynamic propagating behaviour in science and technology. Their second wave of bi-logistic curve that dwells with significant efforts of knowledge-based economic development shows a longer and higher pulse than the first wave.

On contrary, the pursued to develop science and technology by the FDI-leveraging countries such as Singapore and Malaysia has not led to much longer and higher pulse in the second logistic curve. Based on these two distinctive governing approaches, this study highlights the generic evolutionary paths that may be useful as policy lessons, particularly for the developing economies. The findings indicate that institutional dynamics of chaebol conglomerate approach of South Korea and SMI-state network approach of Taiwan are important to drive the self-propagating behaviour particularly in the second wave of bi-logistic curve. Although Singapore, Malaysia and some provinces of China deliberately directed FDI towards selected priority high-technology sectors to develop some indigenous science and technology capabilities, the production of papers and patents witnessed an interesting contrast to the cases of South Korea and Taiwan. This could be largely attributed to the nature of manufacturing-based activities and technological competencies of the MNCs in these economies. Recently, there are significant efforts by the state of these economies to strengthen the learning capabilities in technology. Many universities, research institutions, selected state-owned enterprises and (local-owned) private conglomerate firms were heavily supported to advance applied research activities. Given the efforts in establishing their collective institutions for science and technology production, it is expected that the following pulse (the “third wave”) of the logistic curve and the potential (carrying capacity) for science and technology development will increase.

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