Diffusion Trajectories of Emerging Sciences in Malaysian R&D System

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Abstract

In the last two decades, Malaysia has demonstrated significant economic progress and achieved an impressive growth performance in manufacturing exports as a result of its industrial development policies. In order to achieve higher-value-added sector, Research and Development (R & D) activities are necessary. Since the introduction of the first national science and technology policy (1986-1987) and Industrial Technology Development: a National Plan of Action (1990-2001), the Malaysian government has been committed to develop and building up competencies in learning to advance its R&D activities. This paper aims to analyze the trend of scientific production in Malaysia to indicate some characteristics of its R&D system. Logistic growth function is developed to model the diffusion trajectories of the selected sciences. A time-series of projection of selected technologies is made through logistic curves. In addition, Thailand and Singapore (a country with advanced diffusion of sciences), are included for comparison.

Keywords: diffusion, simple logistic growth function, scientific production, Malaysia

1. Introduction

In recent decades, it has become widely accepted that scientific resources and production play an important role for knowledge-based economic development [1]. The rapid growth in areas of modern technology, such as biotechnology, and nanotechnology, has been fueled by the rapid scientific production in these fields. The word ‘science’ is often used in the literature to represent basic research activities or research carried out by non-industrial institutions such as universities and public research laboratories. Scientific 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. The word ‘technology’ refers to applied research activities or research carried out by industries and private organizations (Grupp [1]and Krahmer and Schmoch [2]). Technology represents the body of knowledge about techniques, and it is characterized by the conception and development of products which are capable of diffusing services and creating a market demand ([3], [4], and [5]). Patents represent the codified part of technological innovation that reflects the interest in commercial exploitation of a new technology (Grupp [6], Kondo [7], and Kumaresan and Miyazaki [8]). According to Schmoch [1], Grupp [3] and Grupp [9], patents as the most frequently revealed indicator for technology reflects inventive and innovative activities for new products or processes in the market.

Many studies (Schmoch [1], Krahmer and Schmoch [2], Grupp [4] and Kumaresan and Miyazaki [8]) used the statistics for papers and patents as the indicators for analyzing the relationship between science and technology[1]. With economic and technological changes, their works suggest stronger connections and higher interactions between science, technology and economic growth. This positive interaction thus creates a virtuous cycle between science, technology and economic growth.

In the recent two decades, Malaysian economy has been growing fast and strong, even after experiencing the Asian financial crisis in 1997 and stagnation in 2000 due to the technology slump (Wong and Goh [10]). The country has transformed its economy from agriculture and primary commodity dependent to manufacturing based and exports driven economies. During this period, it has progressed further to post-industrial knowledge-based economies. The trend is towards growth in high-technology investments, high-technology industries and more highly-skilled labor (Asgari and Wong [11]).

In the transition to a knowledge-based economy, Malaysia has attempted to raise national investments in R&D and researchers since the 1980s to develop the innovation system. The first Malaysian science and technology policy was outlined in the fifth Malaysia Plan in 1986. For the first time in Malaysia 5-year plans', there was a separate budget allocation of RM 414 million for R&D investment. The budget allocation for public R&D activities rose to RM 588 million during the sixth Malaysia plan, RM 1 billion for seventh Malaysia plan and RM 1.413 billion for eighth Malaysia plan (MOSTI [12]). The Malaysian government had identified 3 key research categories for development. Table 1 shows an overall priority setting and budget allocation for each category of research.

Table 1: Research Priority and Budget Distribution for 8th Malaysia Plan.

Research Category	Percentage of Allocation	Priority Areas
Experimental Applied Research	30	• Agriculture and Food Security • Natural Resources and Environment • Social Transformation • Manufacturing and Services • Knowledge Advancement
Prioritized Research	35	• Manufacturing • Plant Production and Primary Products • Information and Communication • Health • Education and Training
Strategic Research	35	• Design and Software Technology

[1] Direct quantitative measures of tacit knowledge transfer between science and technology is impossible. Therefore, proxies such as papers and patents are used as indicators for science and technology respectively. A high citation of papers in the documentation of patents (or vice versa) can be considered to indicate a close relationship between science and technology (Schmoch [1] Stankiewics [5], Grupp[6] and Grupp [9]).

	• Nanotechnology and Precision Engineering • Specialty Fine Chemical Technology • Optical Technology

Source: IRPA Program [13]

Malaysia had committed its resources highly for scientific institutions early in the catching up process and thus successfully improved the growth of scientific knowledge production (see Figure 1). However, at this development stage, the growth of scientific papers (papers indexed by the Institute for Scientific Information, ISI) failed to trigger the interaction between science and technology activities (measured by patents granted by the US patent office) due to poor interaction between universities, industries and the market. The analysis shows a low correlation between scientific production and technological production. Furthermore, Malaysian technological capabilities and development are highly dependent on the scale of inward foreign direct investments (FDI). Closer examination of the data shows that most patents belong to multinationals of American and Japanese origin. These foreign assigned multinational corporations' (MNCs) patents comprise the major share of total patents in the US patent system. MNCs like Motorola and Intel have strong presence in Malaysian electronics and semiconductor firms. The growth of patenting activity from local owned firms is relatively weak compared to that of MNCs. This is a direct result of lack of interest by the local firms in applied research and indigenous technology development.

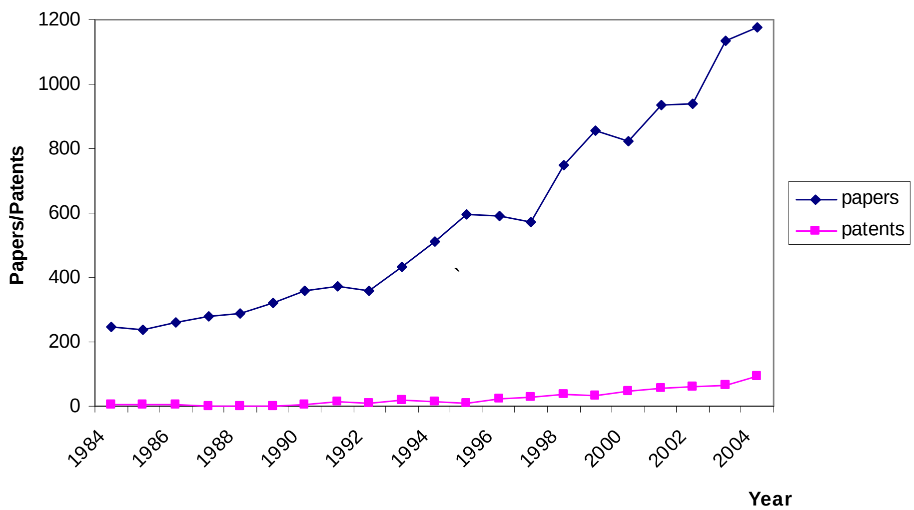

Figure 1: Malaysian Papers and Patents.

As demonstrated in Figure 1, we note that Malaysia has shown a strong pattern of growth with strong diffusion potential of scientific production. However, a systematic approach to the understanding of the diffusion behavior through empirical evidence is still severely lacking. This paper attempts to study the progress of the Malaysian scientific R&D activities by analyzing the trajectories of scientific papers in identified emerging fields of research. Due to the poor nature of

Malaysian patenting activities, this paper focuses only on the scientific production. Technological based activities are not covered in this study.

In this paper, we first attempt to study the cross-country time differences in diffusion of emerging sciences in Malaysia and its neighboring countries, Singapore and Thailand[2]. The trend of papers can be studied through analyzing the correlation coefficient with or without time difference across these countries. The results are useful to identify the time difference of Malaysian scientific diffusion with the diffusions of Singapore and Thailand. Secondly, the logistic growth function is developed to model the diffusion trajectories of selected fields of scientific production in Malaysia. The modeling results are useful to indicate the efforts and interests of the Malaysian scientific community in producing the scientific knowledge. The production by the Malaysian scientific community will be again benchmarked with the production of Thailand and Singapore. The modeling of diffusion of the scientific innovations in these countries not only offers the insights of Malaysian diffusion trajectories of scientific knowledge but also enriches the understanding of the effect of different national innovation system[3] on the diffusion processes and the rate of adoption of the scientific innovations.

2. Methodology

This section discusses the methodology of the study and explains the growth function useful for analyzing diffusion trajectories of science in Malaysia.

2.1 Database keyword search

A set of data has been selected to analyze the performance of the scientific production. The data are the historical series of publications from 1981 to 2005. Search results from National Science Indicators for Malaysia (1980-2005)[ISI Web of Science]database is used to represent the activity for empirical analysis in the scientific production. Key sciences shown in Table 2 are used as proxies to research activities under Malaysian research categories.

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[2] In recent decades, these countries have paid attention to its scientific development plans to develop their knowledge-based economy and catching-up with the Western and Japanese science and technology. Scientific productions of Malaysia, Thailand and Singapore have advanced since 1980s. During the 1990s, their scientific activities became eminent among the South East Asian countries. In addition, Thailand and Singapore have been experiencing similar technological development of Malaysia (the technological capabilities are dependent on the scale of inward FDI). Therefore, Thailand and Singapore are useful to benchmark the performance of Malaysia.

[3]Globalization or regionalization may advance cross country knowledge transfer or influence the process of innovation and learning. However, we still believe that the national innovation system (the networks of communication among agents or institutions) remained important in supporting the process of innovations diffusion. According to Lundvall [14] and Teng *et al.*[15], the external influence for adoption of technology is extremely small. National innovation system is attributed to the development of science and technology and shaped the behaviors of diffusion (Anderson [16] and Watanabe *et al.* [17]). The diffusion patterns are subjected to the coefficients of internal influence (national agents and institutions). Therefore, logistic growth function (the concept is based on internal influence) is opted in this study to model diffusion of scientific innovation.

Table 2: Research Categories and Selected Key Sciences Search in ISI Web of Science Database.

Research Category	Selected key Sciences
Experimental Applied Research	• Agriculture/agronomy • Environment Engineering/Energy • Mathematics • Civil engineering
Prioritized Research	• Information technologies and communication system (ICT) • Pharmacology and Toxicology • Engineering management • AI, robotics and automation • Electrical and Electronics • Biotechnology and applied microbiology • Material Science and Engineering
Strategic Research	• Computer science • Physical chemistry • Chemical engineering • Mechanical engineering

2.2 Correlation Coefficient

The trend of scientific papers can be studied by analyzing the correlation coefficients with or without time difference between the Malaysian trend and its neighboring countries' trends (see Kondo [7]). The time difference can be identified quantitatively through analyzing the values of correlation coefficients between the two trends. The highest value indicates the similar trend of two countries. The relation is expressed as follows;

$$Y_t = \mathrm{A} + \mathrm{B}x_{t-n}$$

where:

Y: number of Malaysian scientific production
A: miscellaneous/constant
B: elasticity
x: number of scientific production in its neighboring countries
t: time (year)
n: value that adjusted with or without time difference

2.3 Logistic Growth Function

Technological development characteristic usually shows an ‘S-curve’ growth pattern ([Griliches [18], Twiss [19], Rogers [20]). The data obtained can be assumed that it will continue to grow along an S-curve which can be fitted to the data from its emergence to the present development and extrapolated into future growth or saturation to a limiting level. This diffusion process is much alike to the infection process of an epidemic disease and these processes are characterized by S-curved growth pattern (Rogers [20] and Phillips [21]). Various S-curve models can be used to describe the diffusion behaviors. However, among these models, the simple logistic growth function that originates in the biological realm[4] is often used to model the case of diffusion of science and technology. This is mainly due to its rich empirical description and its devices are found effective in capturing the changing nature of science and technologies (Devezas *et al.*[22], Martino [23] and Bengisu and Nekhili [24]). Thus, the simple logistic function is opted in this study to model and explain the diffusion processes of sciences. The appendix elucidates the suitability of the function to fit the data set.

The simple logistic growth function is presented as follows:

$$p_t = \frac{L}{1 + ae^{-bt}}$$

where:
p=value of the technological parameter
t=time
L=the natural limit or carrying capacity
a and *b* are coefficients of carrying capacity and time respectively

To plot the S-curve on log-linear model,

$$L = p_t(1 + ae^{-bt})$$

$$\frac{L}{p_t} - 1 = ae^{-bt}$$

$$\log(\frac{L}{p_t} - 1) = \log a + bt$$

The natural limit of diffusion or carrying capacity is estimated through the data linearization technique (see Mathew [25]). Fitting the logistic curve to data is presented through judicious selection of L[5].

According to Twiss [19] and Rogers [20], the S-curve can be considered as consisting of three stages:

1) Incubation
2) Rapid growth
3) Maturity lengthy

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[4] The function is also commonly used to study population growth, a metaphor of biological realm such as evolution, selection, life cycle and survival of the fittest.

[5] A value that is selected through least square line and useful for calculating the coefficients of *a* and *b*.

As shown in Figure 2, the incubation period that is characterized by slow growth in the production of science is lengthy. Scientists and academic researchers in the science system are first not convinced to contribute their intellectual inputs to a new scientific field of research. Once a breakthrough idea that is gradually accepted as providing solution to research problems, the growth raises rapidly until its approaches the physical limit or carrying capacity. The idea stimulates interests of many scientists to contribute their intellectual inputs. The growth of papers approaches the physical limit when major research problems or theoretical questions are solved and answered (Roger [20], pg. 38-105).

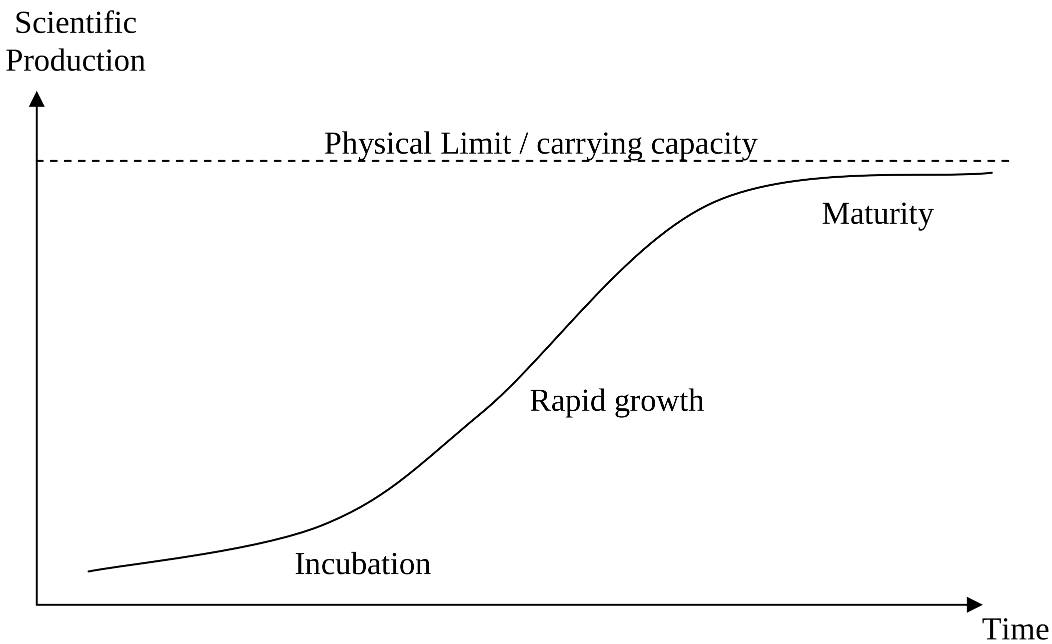


Figure 2: The S-curve of Scientific Progress.

3. Results and Discussion

3.1 The changing level of scientific production in Malaysia and its neighboring countries

According to Kondo [7], the character of scientific knowledge diffusion activities can be analyzed by observing the changes in the papers of general articles in journals. Table 3 shows the correlation analysis of time-lag between Malaysia and Singapore in the selected key sciences. The Malaysian trend of diffusion activities is in the same phase as the Singaporean trend (no time-lags) in the field of environment engineering and energy, civil engineering, ICT and electrical and electronics. Malaysia lagged behind Singapore by one to two years with regard to the trend of computer science, physical chemistry and chemical engineering. In the field of AI, robotics and automation, Singapore was ahead of Malaysian trend by four years in R&D and information diffusion activities. On the other hand, the Malaysian trend was a little ahead of the Singaporean trend in pharmacology and toxicology, engineering management, biotechnology and applied microbiology, mechanical engineering and material science and engineering fields. This result indicates that Malaysia has shown great interest and paid attention in selected key sciences as that of Singapore since the 1980s. The similar growth pattern of Malaysia and Singapore occurred because these selected sciences were assumed to be the heart of knowledge-based economic development.

Table 3: Correlation Analysis of Time-lags for Papers on Selected Emerging Scientific Production (Malaysia and Singapore).

	R^2							
Malaysia's lag (years)	-3	-2	-1	0	1	2	…	4
1. Agriculture/agronomy		-	-	-	-	-		
2. Envir. Eng./Energy		0.3110	0.8301	**0.8447**	0.8212	0.7921		
3. Mathematics		0.0177	0.0009	0.0014	0.0051	0.0009		
4. Civil engineering		0.2455	0.3770	**0.4659**	0.4477	0.3852		
5. ICT		0.6680	0.7080	**0.7714**	0.6944	0.6821		
6. Pharma. and toxicology		**0.7643**	0.7067	0.7445	0.4762	0.3865		
7. Eng. management		**0.8492**	0.7818	0.7595	0.7521	0.6453		
8. AI, robotics, automation		0.5748	0.4866	0.5571	0.5365	0.5732	…	**0.6251**
9. Electrical & Electronics		0.6989	0.7043	**0.7340**	0.6959	0.6607		
10. Biotech., ap Microbio	**0.8608**	0.7701	0.7387	0.7184	0.5403	0.4652		
11. Computer science		0.6769	0.6380	0.7015	**0.7127**	0.5065		
12. Physical chemistry		0.8890	0.9096	0.9111	**0.9232**	0.8663		
13. Chemical engineering		0.9188	0.8735	0.8777	0.8771	**0.9375**		
14. Mechanical engineering		**0.7920**	0.6688	0.7437	0.6853	0.6434		
15. Material Sci. and Eng.		0.8672	**0.9338**	0.9274	0.9229	0.8511		

Note: Highlighted value shows the highest coefficient one in each row.

In the field of mathematics, the correlation coefficient was the lowest among other fields. The trend of Malaysian information diffusion in mathematics was significantly low compared to Singapore. The Malaysian trend has shown almost no interest in developing mathematics' research activities (see Figure 3).

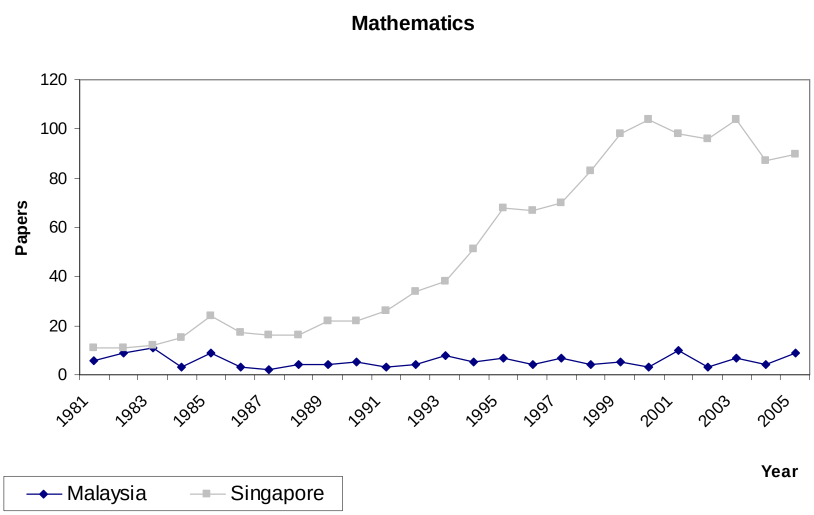


Figure 3: Papers Produced in the Field of Mathematics.

As shown in Table 4, the Malaysian trend of scientific knowledge diffusion activities was in the same phase as that of Thailand (no time-lags) in the field of engineering management and mechanical engineering. Malaysia lagged behind Thailand by one to two years with regard to the trend of environmental engineering and energy, civil engineering, physical chemistry and material science and engineering. The Malaysian trend was a little ahead of the Thailand's trend in the fields of agriculture and agronomy, pharmaceutical and toxicology, AI and robotics, electrical and electronics, biotechnology, computer science and chemical engineering. In the race with Malaysia and Singapore to knowledge-based economy, Thailand has paid attention in the similar fields for development. The result does not show any significant lags of attention and diffusion of these sciences with Malaysia and Singapore.

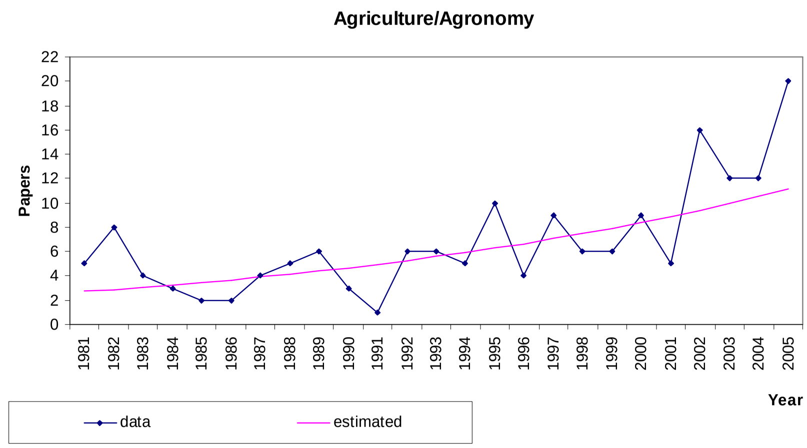
Table 4: Correlation Analysis of Time-lags for Papers on Selected Scientific Production (Malaysia and Thailand)

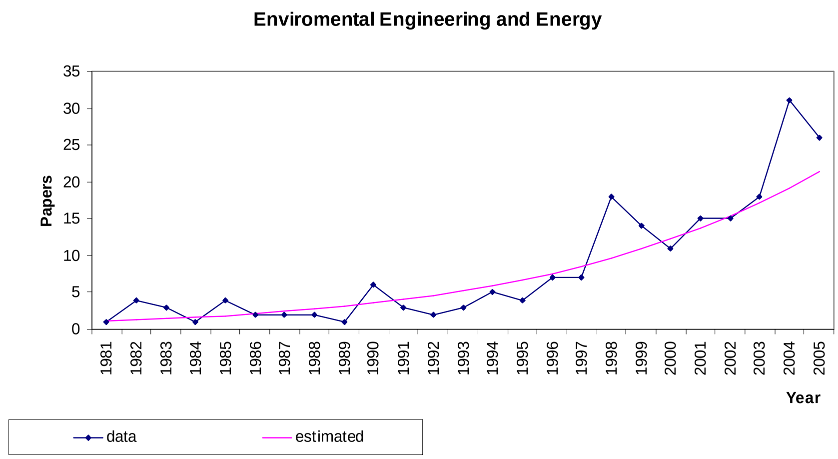
				R^2		
Malaysia's lag (years)	-3	-2	-1	0	1	2
16. Agriculture/agronomy		0.5079	**0.5922**	0.4870	0.3356	0.2265
17. Envir. Eng./Energy		0.2616	0.3824	0.4007	0.3973	**0.4045**
18. Mathematics		0.0079	0.0000	0.0441	0.0195	0.0793
19. Civil engineering		0.0550	0.2801	0.4179	0.4094	**0.4640**
20. ICT		0.7210	0.7685	0.6879	**0.7746**	0.7107
21. Pharma. and toxicology		0.5230	**0.5416**	0.5295	0.3711	0.3036
22. Eng. management		0.4627	0.5027	**0.7299**	0.6020	0.5118
23. AI, robotics, automation	**0.8605**	0.5404	0.6744	0.5297	0.6612	0.4577
24. Electrical & Electronics		0.6796	**0.8497**	0.7977	0.7204	0.7654
25. Biotech., app. Microbio		0.6498	**0.6724**	0.6153	0.5553	0.5349
26. Computer science	**0.6950**	0.4462	0.2685	0.6001	0.5850	0.4398
27. Physical chemistry		0.7881	0.7704	0.7709	0.6640	**0.8613**
28. Chemical engineering	**0.9169**	0.9148	0.8966	0.8974	0.8941	0.8646
29. Mechanical engineering		0.8474	0.8775	**0.9187**	0.8453	0.7806
30. Material Sci. and Eng.		0.7061	0.7404	0.7542	0.7806	**0.9221**

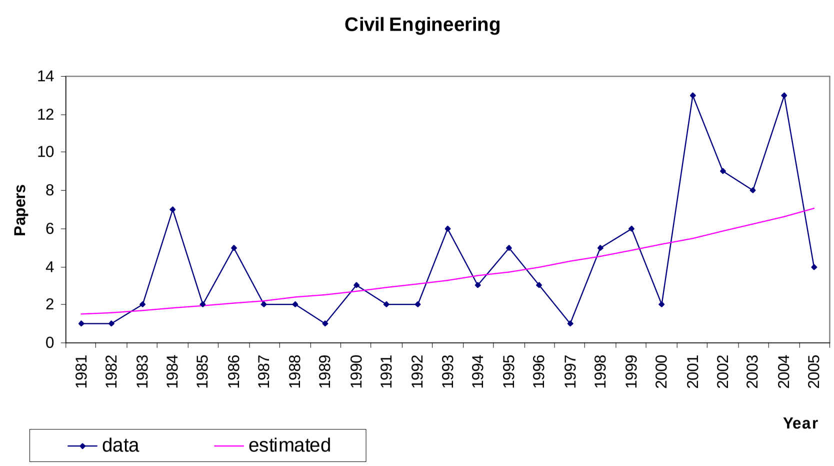
3.2 Diffusion Trajectories of Scientific Research

The result of the estimated growth functions for the case of Malaysia is firstly discussed. Comparisons are then made with the results for Thailand and Singapore.

Figure 4 demonstrates the diffusion trajectory of Malaysian sciences categorized under experimental applied research. The curves indicate that the emerging trend is expected to continue in agriculture/agronomy, environment and engineering and energy and civil engineering. There are positive signs that these research activities will rise rapidly in the near future. The growth can be fuelled by conducting more basic R&D activities. However, the trend of mathematical papers indicates insignificant efforts in developing the capabilities. The trend in the diffusion trajectory for mathematical papers is almost constant, demonstrating a static nature of the research activities in the field of mathematics.







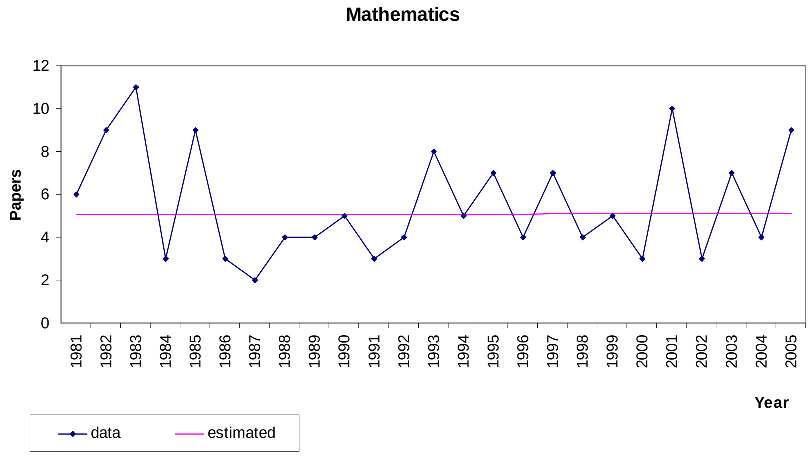
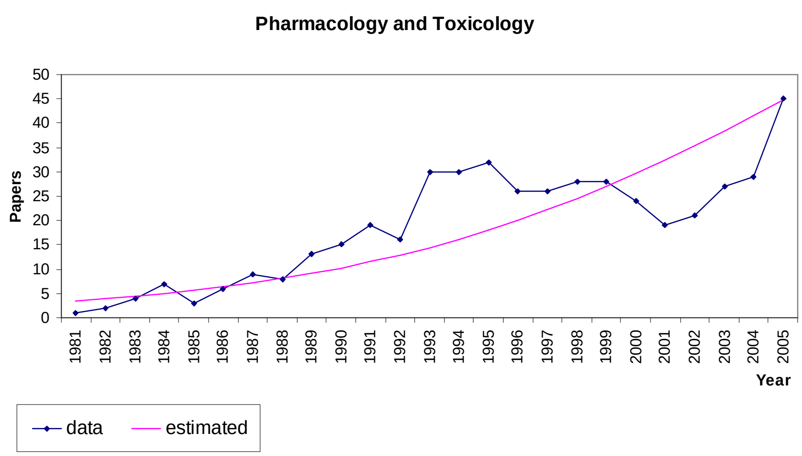
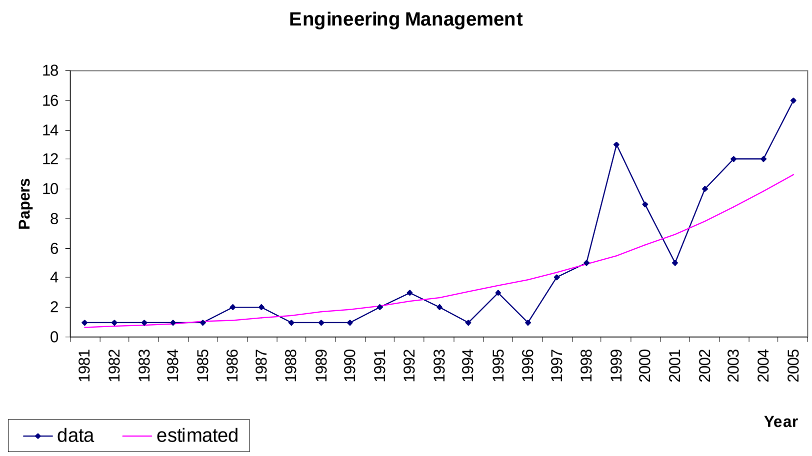


Figure 4: Growth Curves of Sciences in Experimental Applied Research.

Figure 5 illustrates the case of prioritized research of Malaysia. Similarly with the case of experimental applied research, the curves indicate that the emerging trend and growth is expected to continue in pharmacology and toxicology, engineering management, AI, robotics and automation, electrical and electronics engineering, biotechnology and applied microbiology and material science and engineering. Many universities followed the national agenda to further develop their generic national scientific capabilities and raised the relevant scientific output successfully.

ICT is experiencing the premature stage. The government of Malaysia has increased the efforts in upgrading the infrastructures to develop ICT since the launching of Multimedia Super Corridor project in 1996. To our disappointment, the growth of its scientific activities has not been promising. The production remained low, despite ICT being recognized as driver to the economic growth. This field somehow failed to catch-up with the scientific competency ladder.

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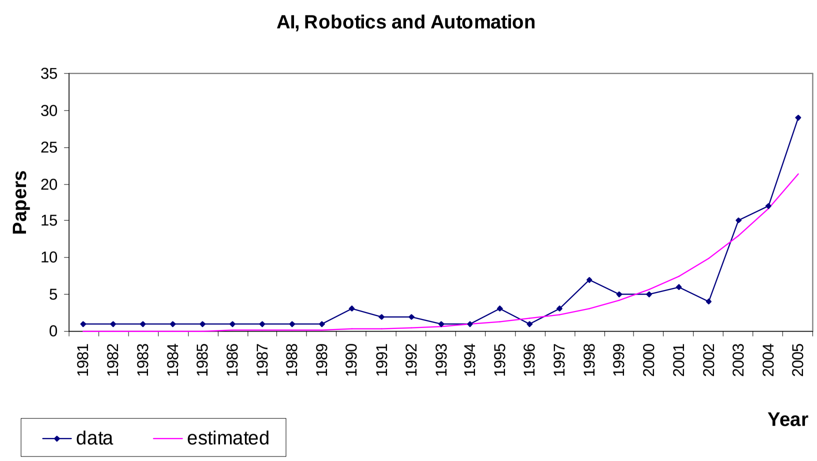
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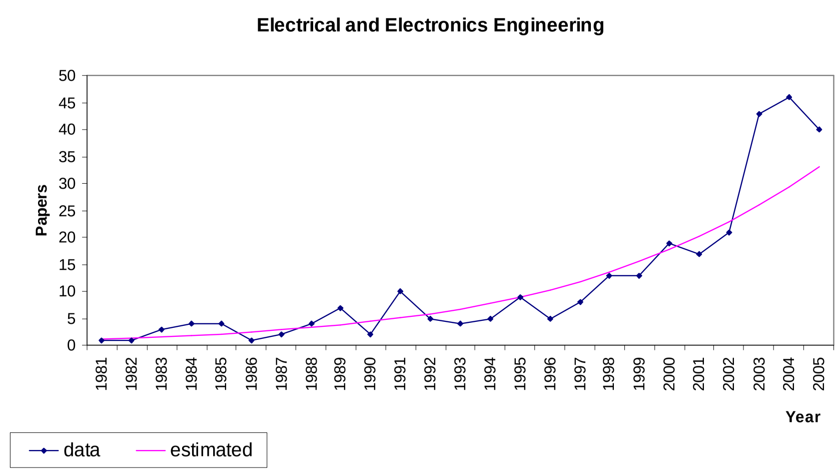
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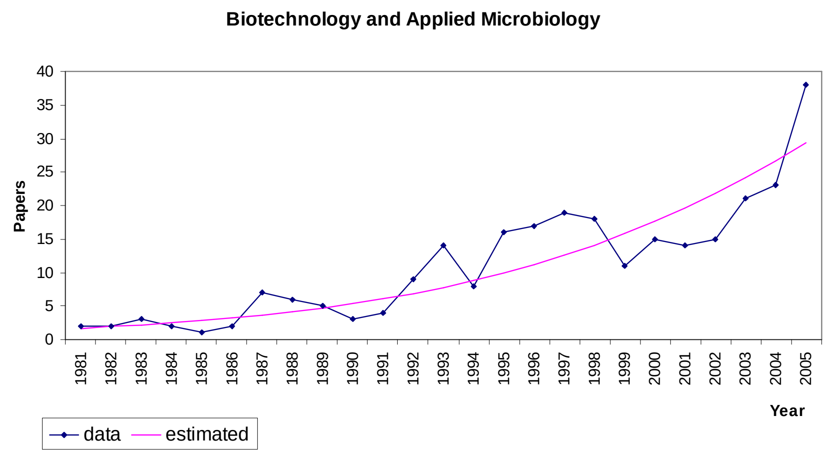
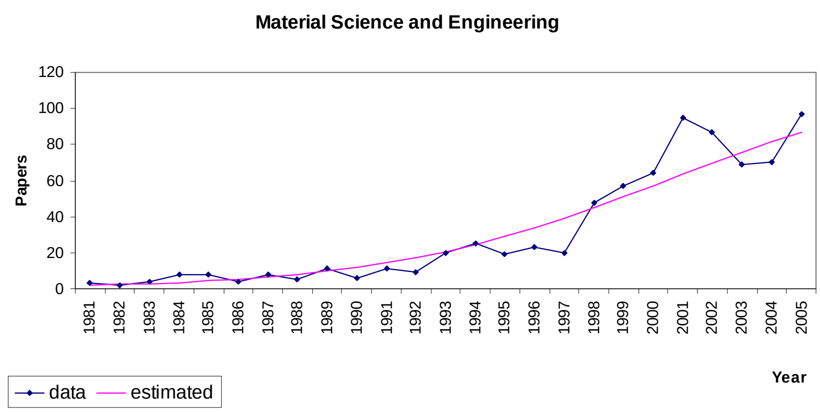




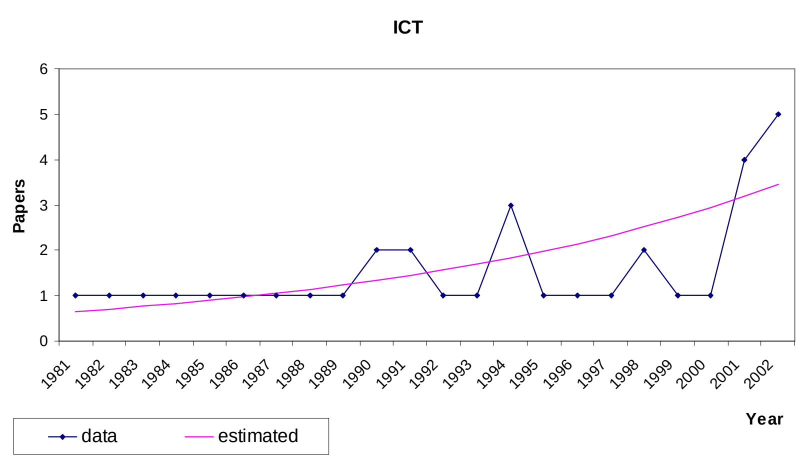
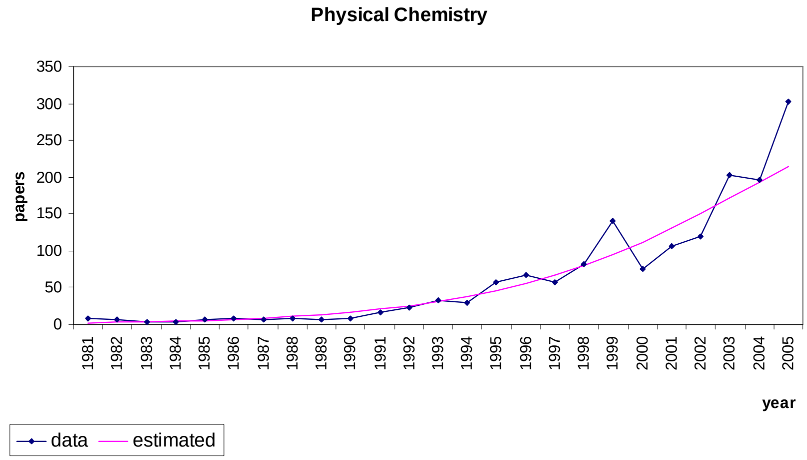
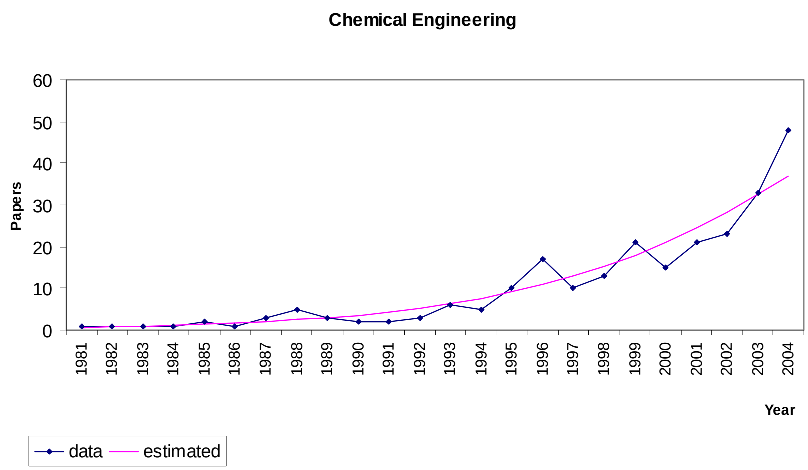
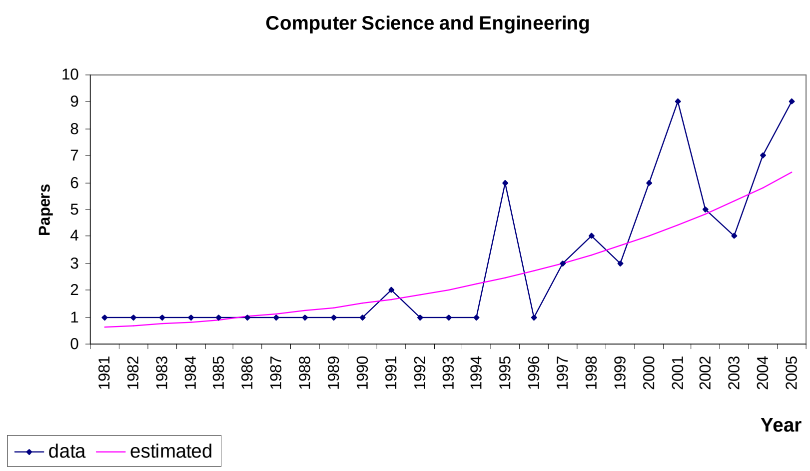


Figure 5: Growth Curves of Sciences in Prioritized Research.

Figure 6 illustrates the case of Malaysian strategic research category. All sciences under this category are experiencing rapid growth since the early 1990s. In the early 1990s, the government had foreseen the need of scientific outputs in this category to support knowledge-based economic development. As a strategic plan, there was increased investment in university R&D to produce scientific results and support national basic R&D programs to develop scientific capabilities.







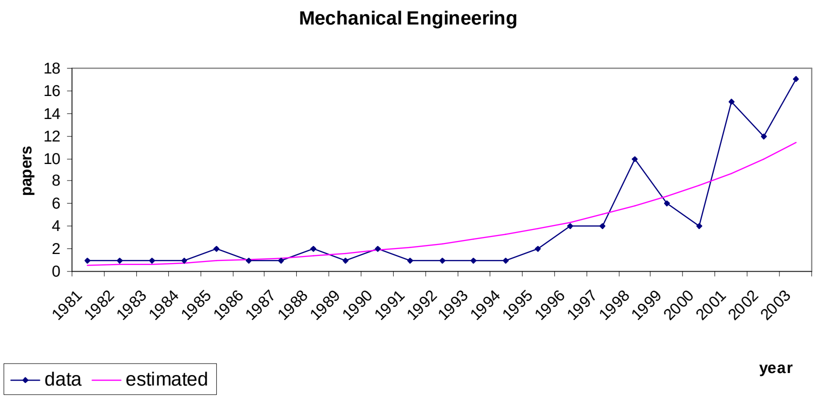


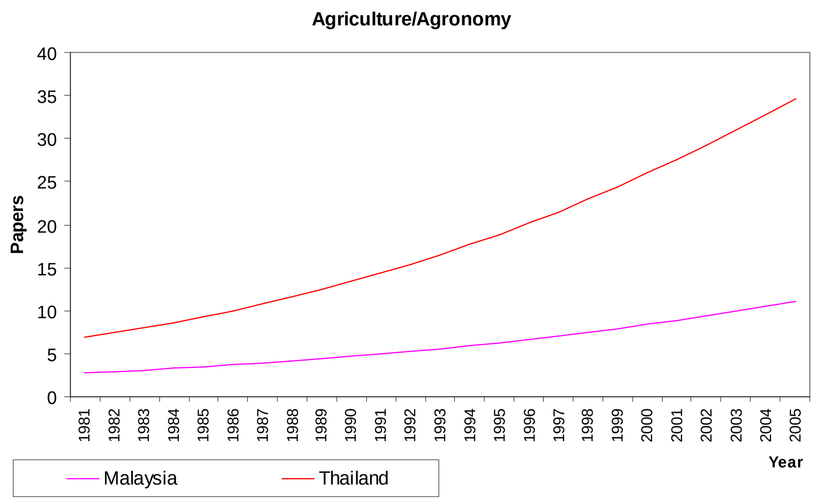
Figure 6: Growth Curves of Sciences in Strategic Research.

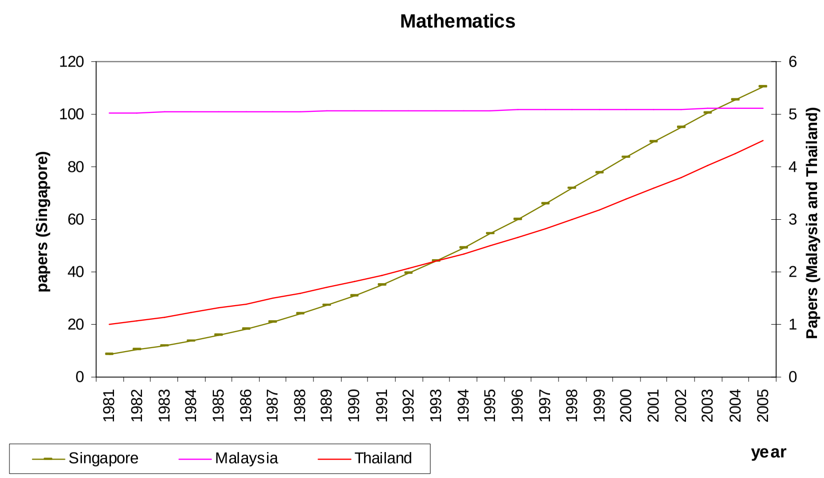
Generally, Malaysian scientific production grew considerably over the decade and it is expected that the diffusion emerges with a great potential for this optimistic forecast. However, Malaysian emerging trends in scientific production is significantly behind Singapore. In addition, Thai diffusion of scientific innovations emerges with a greater potential than that of Malaysia (see Figure 7, Figure 8 and Figure 9).

Although Malaysia, Thailand and Singapore had committed their resources for development of their innovation system and accelerating scientific production since 1980s[6], it seems that the model of innovation system that adopted by Singapore and Thailand were more successful. Their rapid growth of scientific outputs and outperforms Malaysia in almost all key sciences. Figure 7 illustrates the case of experimental applied research. Thai agriculture/agronomy[7] papers production has witnessed a steady increase and significantly outpaced Malaysian papers since before 1981. Singapore has been leading Malaysia and Thailand in the production of mathematics and environment engineering and energy. In comparison with the exponential growth of Thai diffusion of mathematics papers, it is clear that the Malaysia mathematics trend only tends towards a constant development.

Among these countries' changing level of R&D results, Singapore has developed its competencies in almost all prioritized research activities and continues its dominance in terms of outputs. In particular, for the two fields of pharmacology & toxicology and material science & engineering, Malaysia was outpaced by Singapore in 1997 and 2004 respectively (see Figure 8). Furthermore, it can be observed that Singapore is experiencing the second wave[8] of scientific development in the electrical and electronics engineering sector. This cycle is most likely associated with the market pull cycle[9].

[6] There is low time difference of scientific diffusion between Malaysia, Thailand and Singapore
[7] Singapore has not involved in agriculture/agronomy research due to its geo-economic structure (island city state).
[8] Bi-logistic growth function is used to model the diffusion trajectory. For details of a bi-logistic growth function, see [17].
[9] According to Schmoch [26], the first boom reveals the science push cycle followed by the second boom that is associated with the market pull cycle.





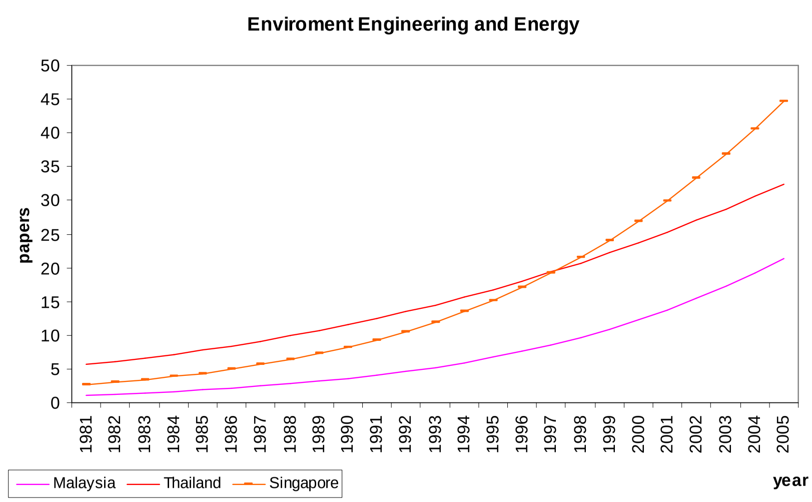
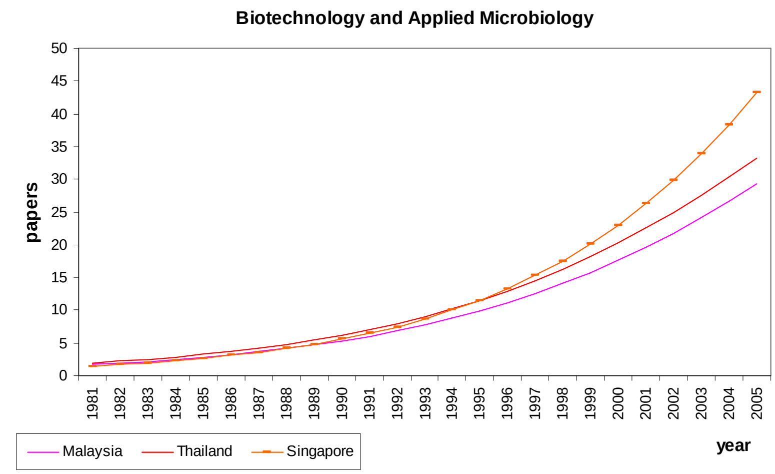
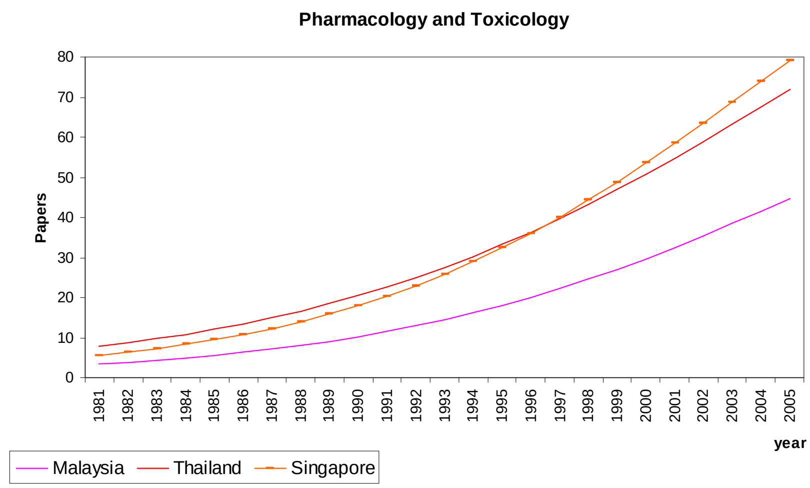
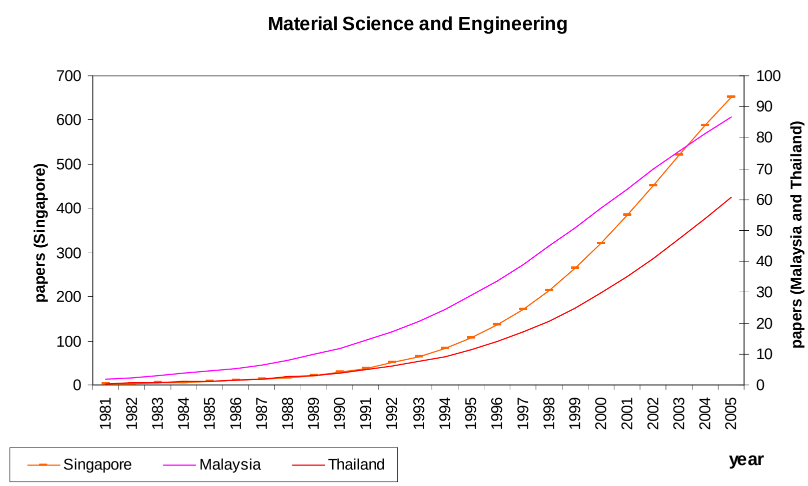


Figure 7: Growth Curves of Selected Sciences in Experimental Applied Research.

Thailand shows a greater emerging potential of diffusion process than that of Malaysia. The current national interest fields, particularly for the case of biotechnology and applied microbiology, and pharmacology and toxicology and electrical and electronics engineering are lagging behind the Thailand in scientific production.







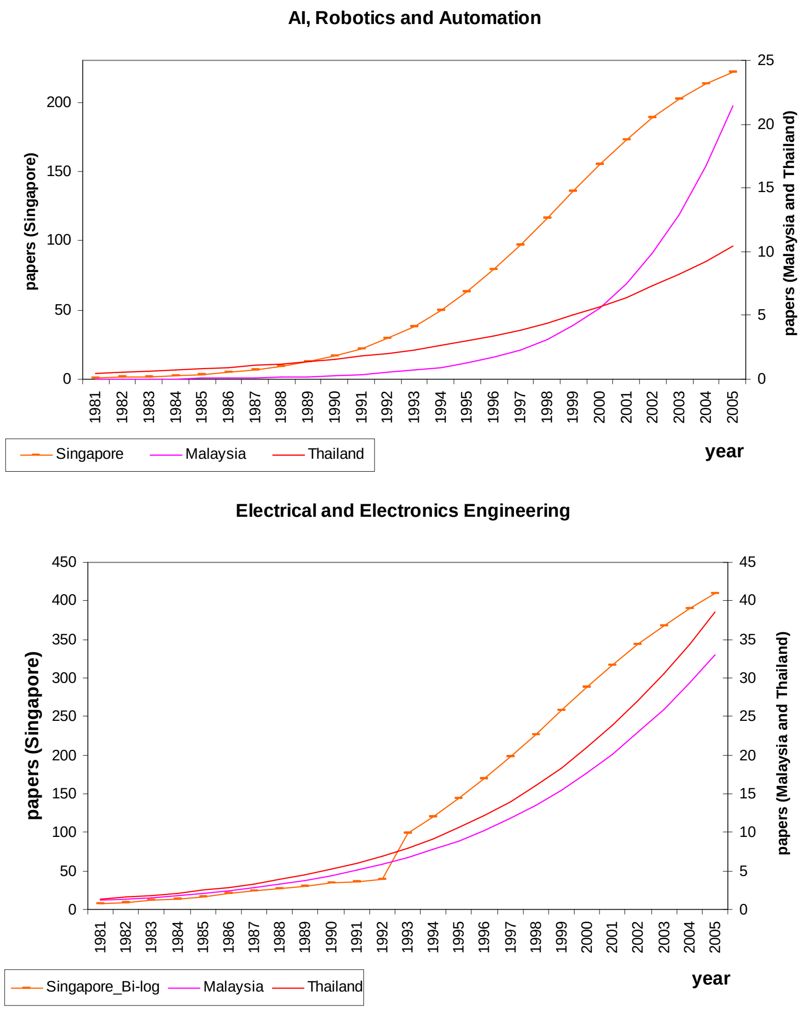
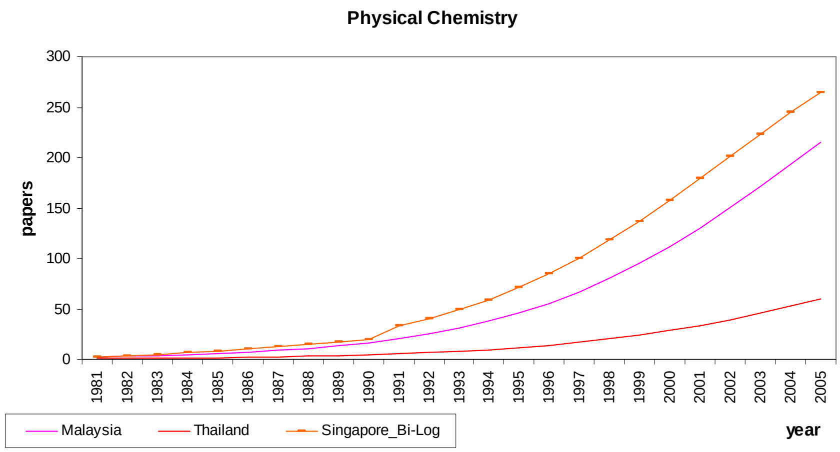


Figure 8: Growth Curves of Selected Sciences in Prioritized Research.

As demonstrated in Figure 9, Malaysia and Singapore also show a greater emerging potential of diffusion process in physical chemistry. In chemical engineering field, Singapore outperforms Malaysia and Thailand and Malaysia is light ahead of Thailand.

4. Conclusions

In the recent decades, Malaysian government has introduced and launched various programs to strengthen the Malaysian innovation system to complement the R&D activities in Malaysia. These laudable efforts have successfully advanced the scientific production and show a great emerging potential of technological diffusion process.



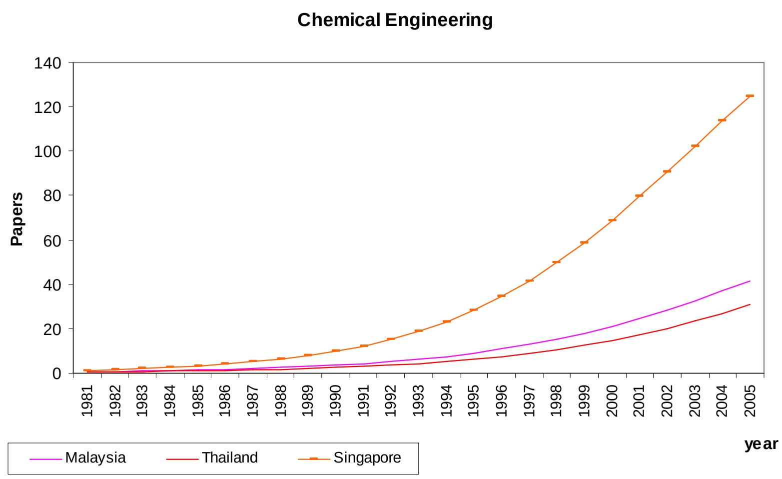


Figure 9: Growth Curves of Selected Technological Fields in Strategic Research.

Since the 1990s, Malaysia, Thailand and Singapore were identical in the diffusion of scientific knowledge in the region of South East Asia. However, Singapore and Thailand outperforms Malaysia in term of scientific production and the gap is expected to widen if there is no progress of perfection in Malaysian innovation system.

5. Managerial and Policy Implications

A number of implications emerge from the findings of this study as follows:

1. The pipeline model of innovation whereby growth of scientific knowledge production can be attributed solely to development of human workforce and investments in R&D is flawed as demonstrated by the examination of scientific publication productivity between Thailand and Malaysia. Thailand, a nation that has only 292 FTE (full time equivalent) per million population and a research intensity (R&D expenditure as a percentage of GDP) of 0.26 published more scientific papers than Malaysia which has more R&D personnel and

expends more on R&D (see Table 5). More investments in R&D do not necessarily guarantee increased scientific productivity. Research productivity as measured by publications is a product, among others, of sound institutional practices that fosters and rewards personnel that are active in publishing as well as engages in building networks among researchers not only within the same organization but also across organizations.

2. Merging education, scientific and entrepreneurial activities within universities would promote growth of scientific knowledge production. According to Van Looy *et al.* [28], publication output from university's scholars who were involved in patenting activities published significantly more than scholars who have no involvement in patenting activities. Finding from Bernandas and Albuquerque [29][28] and Van Looy *et al.* [28] show how scientific and technological activities were mutually reinforced.

3. Despite having almost similar number of research personnel, the scientific publication productivity of researchers in Singapore far outstrips that of Malaysia. This disparity is widening in almost all major scientific fields. Although the scientific publication productivity level of Malaysia, Singapore and Thailand was almost similar in the early 1990s, the divergence in productivity levels has since taken place and the pace has increased of late. The divergence of scientific productivity between Thailand and Malaysia, although not marked, also points to higher levels of productivity attained by Thailand. These disparities suggest that the management of the scientific enterprise at both the national and institutional levels assume importance in determining the productivity of the organizations that are the beneficiaries of public research funding. Studies (see MOSTI, 2008) have revealed that there is unevenness in publication productivity among the public funded universities in Malaysia and that public research institutions are weak in publishing. These findings underscore the need for enhanced research leadership and institutional reforms of these organizations. Without a serious examination as to the causes of the poor scientific publication record, pumping more resources into the scientific enterprise may not only fail to generate increased knowledge production as reflected in scientific publications but, worse still, be a drain on scarce resources.

Table 5: R&D Expenditure, Research Workforces and GDP per Capita in 2004

	R&D (R&D/GDP)	Workforces (FTE/million populations)	GDP/capita (US$)
Malaysia	0.60	503	4952
Thailand	0.26 (2003)	292 (2003)	2578
Singapore	2.36	4997	25540

Source: UNESCO [27].

Appendix:

Simple logistic growth function and Gompertz function are two models that commonly used by extrapolation techniques practitioners. Martino [23] and Franses [30] advised the practitioners to opt for a preferred model that fit to the data set. They proposed *t*-regression to opt for a preferred model:

$$\ln(\Delta \ln Y_t) = \alpha + \beta t + \gamma t^2$$

Gompertz curve is linear in *t* regression model and the expression for logistic curve is non-linear in *t*. If γ is significantly different from zero, the model can conclude that the logistic is a better model for the data then Gompertz. **Table A1** shows the coefficient γ of t^2 is highly significant (significantly different from zero). Therefore, logistic process is used to process the data set.

Table A1: Significance of Regression Model of Malaysian Scientific Production

Coefficient Value	α	β	γ
1. Agriculture/agronomy	-2.93	11.74	-0.49
	(-0.19)	(2.44)	(-1.59)
2. Environment Engineering/Energy	4.96	-1.04	0.076
	(1.93)	(-3.02)	(5.90)
3. Mathematics	8.01	-0.52	0.02
	(4.93)	(-1.81)	(1.83)
4. Civil engineering	2.86	-0.20	0.018
	(1.58)	(-0.61)	(1.52)
5. Information technologies and communication system (ICT)	2.83	-0.57	0.032
	(2.80)	(-3.21)	(4.85)
	-3.89	2.45	-0.04
6. Pharmacology and toxicology	(-1.05)	(3.72)	(-1.70)
	2.431	-0.56	-0.041
7. Engineering management	(2.01)	(-2.52)	(4.99)
	4.92	-3.19	0.56
8. AI, robotics and automation	(0.67)	(-1.04)	(2.06)
	7.95	-1.93	0.12
9. Electrical and Electronics	(2.41)	(-3.92)	(5.92)
	1.67	0.10	0.04
10. Biotechnology and applied microbiology	(0.61)	(0.10)	(2.00)
	1.39	-0.21	0.02
11. Computer science	(1.51)	(-0.27)	(3.10)
	31.6	-9.88	0.72
12. Physical chemistry	(2.01)	(-3.54)	(6.93)
	8.04	-0.34	0.16
13. Chemical engineering	(2.17)	(-3.55)	(6.41)
	5.72	-1.56	0.09
14. Mechanical engineering	(2.67)	(-4.09)	(6.47)

15. Material Science and Engineering	8.09 (1.19)	-2.16 (-1.79)	0.23 (5.12)

Note: Figure in the parenthesis indicates t-value.

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