An Economic Analysis of Technological Diffusion in East Asia

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Abstract
This paper discusses an underlying rationale underpinning the need to establish new regimes to enhance the prospects for technology diffusion in East Asian economies. This rationale contradicts neo-classical ideas on technological diffusion. Data analysis indicates that most East Asian economies, except Japan, lag behind in R&D. However, IT production/ consumption and human capital are conducive to diffusion processes. A "ecosystem-type" regime is proposed to promote widespread diffusion and growth in East Asia economies. This proposed system is viable and robust.

I. Background

It is commonly believed that economies grow and advance as scientific research and development activities yield new products and process innovations. Innovations are seen as key milestones creating improved competitiveness and global success. This is true at firm level environments too. From a macroeconomic perspective, to enjoy sustainable increases in productivity and economy-wide increases in living standards, the process of innovation diffusion is crucial. Freeman (1989) argues that "ultimately, it is only the successful diffusion of innovations which leads to perceptible and widespread effects on the growth of productivity or trade competitiveness and on aggregate economic performance". The Singaporean Prime Minister, Goh Chok Tong asserts that "for the economy to have depth, R&D must be strong". In recent decades healthy growth in Asia/ Pacific countries has been observed. In particular, East Asia's maturing economies (Taiwan, Singapore, South Korea and Hong Kong)[1], have experienced outstanding manufacturing achievements and overall economic growth. These successes do not stem purely from numerous and substantial technological discoveries. Instead, a complex mixture of favourable elements such as, flexible and competitive manufacturing processes, abundant skilled labour supplies, effective education systems and the development of fundamental socio-economic infrastructures. If we follow rigid logic regarding the direct association between technological levels and growth, it is impossible to uncover the numerous economic miracles displayed in the region. Marching towards the millennium, economic activities may become overbalanced with the large advances in science and technology, telecommunication and other information superhighways outweighing the involvement of human beings. This crucial discrepancy is the mainspring of the subsequent analysis. The paper is structured as follows: first a concise review of

[1] This grouping of Asian economies, so-called Tiger Economies, are also named as newly industrial countries (NICs) throughout this paper.

Mansfield's model is given. Secondly, an analysis of the economic data reflecting recent trends in technological diffusion for global and regional cases is undertaken. Thirdly, the potential impact of global trade on technology diffusion and spillovers is analysed. The last part proposes a new regime, which is crucial for understanding the dynamic changes occurring in East Asia.

II. The Neo-Classical Model Of Diffusion

The pioneering work regarding the neo-classical model of technological diffusion was proposed by Mansfield (1961) based on the foundations laid by Griliches's (1957) study. Mansfield's (ibid.) study created a profound impact in the literature and was subsequently applied extensively as seen in David's (1969) probit model, Romer's (1977) testing procedures for several engineering industries, the discussion of the role of firm's size in Davies (1979) model and the role of innovation-supply industries in Stoneman and Ireland's (1983) work.

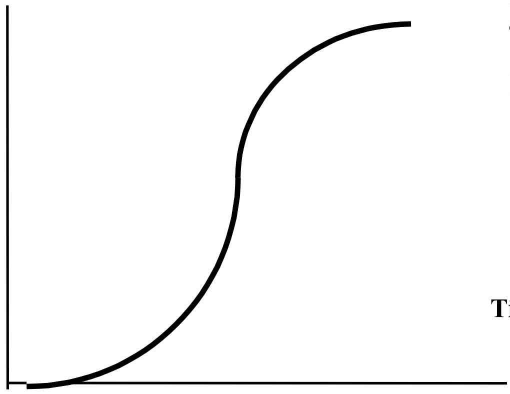


Diagram 1:
Mansfield's S-shaped Diffusion Curve

The Mansfield's model of diffusion is embodied in the S-shaped curve shown in Diagram 1. The shape of the curve indicates that as time passes, initially very few firms try new innovations. This is caused by the initial lack of confidence in innovation performance, uncertainty about the required capital input and other necessary adjustment costs. Diffusion, indeed, is essentially a learning process. With more market information and knowledge available, together with mounting rivalry, more firms gradually follow industry trends and adopt new technological advances. The model also can be represented mathematically as follows:-

$$\frac{M(t+1) - M(t)}{N - M(t)} = b \frac{M(t)}{N} \qquad [1]$$

where, N is the number of firms in an industry; M is the number of firms adopting the new technology and t is time. M(t+1) - M(t) refers to the number of firm which intend to adopt new technology in a given time period, N-M (t) represents the proportion of firms not having adopted the new innovation; b is the coefficient of the ratio of firms in an industry which already adopted the new innovation (M(t)/N).

Obviously, predictions based on this model might ignore other crucial factors at play such as the influence of advertising and other promotional devices, social and cultural values, behavioural patterns and labour union practices. These are limitations on the models predictive ability. Equally important are influences on diffusion caused by endogenous features in an industry, e.g. leaders and followers. Moreover, internal firm structures may limit capacity for diffusion too. This results in different speeds of response in utilising newly innovated know-how between firms.

Diffusion of knowledge occurs sporadically and is unrestricted by national boundaries. As economies evolve, speeds of innovation diffusion outstrip the existing rates. This concept was highlighted by Killingsworth (1963). He argued that based on the current fact that improvements in communications and more accurate methods of deciding replacement of old technologies and higher receptivity towards new ideas occur as economies advance. He claims that innovation spreads more rapidly now than in the past. However, in the past, economic literature concerning diffusion focused on inter-firm and inter-industry differences. The literature seldom emphasised the need to examine the spread from national or global perspectives. Given this fact, plus the recent dynamic developments in East Asia, there is a need to search for a new approach which captures the advancement of the technological spread and identifies new regimes which may enhance diffusion processes.

III. Comparative Economic & Industrial Performance

(% change year on year)

	1991	1992	1993	1994	1995	Average 91-95
Japan	1.7	-6.1	-4.5	0.9	3.2	-0.96
Singapore	5.4	2.5	10.2	13.0	10.3	8.28
Taiwan	7.5	4.5	3.7	6.7	4.2	5.32
South Korea	9.6	5.8	5.2	11.0	11.8	8.68
Malaysia	12.3	8.6	9.6	12.1	12.2	10.96
Thailand	7.2	10.4	10.5	9.2	11.9	9.84
Philippines	7.6	1.6	20.3	16.4	16.7	12.52
Indonesia	1.6	-5.2	0.1	2.5	3.5	0.5
China	11.8	20.2	23.7	18.3	13.5	17.5

Table 1: Industrial Outputs In South East Asian Countries

Source: Data from Asia Macroscope 1997, BZW Asia Limited

Note: Countries are listed in descending order according to levels of GNP or GDP per capita

Table 1 shows that most Asian economies have been enjoying healthy growth in industrial production, apart from the dominant Japanese economy, which suffered detrimental growth phases in the world recession in early 1990s'. Interestingly, the growth of industrial output in China has rocketed with an staggering average rate of growth of 17.5%, followed by Malaysia (12.52%) and the Philippines (10.96%). Inspection of Tables 2 and 3 shows that large scale R&D expenditure seldom originates in Asia, except perhaps in the well-established Japanese manufacturing enterprises. In technical terms, the recent economic development in East Asia is based on western and Japanese technological platforms. The competitive edge created by emerging Asian economies were largely built upon upscaling and downscaling of the available technology to suit local manufacturing/ industrial processes[2].

According to Table 2, in recent years, companies with highest R&D are still dominated by G7 countries such as US, Germany and Japan. To analyse global diffusion trends, it is clear that one can either isolate leading investors in R&D or, the

[2] This is similar to what Japanese economy did during its initial stages of technological development in 1950s' through to the 1970s'.

number of patents obtained by the major firms in each industrial sector. However, simply equating these company R&D expenditures as focal achievements of world innovations produces an inconsistent picture. Moreover, this view may lead to fundamental errors when assessing diffusion processes occurring in East Asia.

Company	1994	1993	1992	1991	1996*	1994*
General Motors (US)	4.50	3.85	3.78	3.76	5.6	4.5
Ford (US)	3.33	3.21	2.77	2.38	5.8	4.1
Siemens (Germany)	3.10	3.17	3.46	3.25	7.7	8.9
Hitachi (Japan)	3.10	3.21	3.28	3.14	6.1	6.5
IBM (US)	2.16	2.83	3.25	3.20	5.2	5.3
Daimier-Benz (Germany)	2.14	3.73	3.84	3.46	5.2	5.0
Matasushita (Japan)	2.45	2.57	2.68	2.46	5.9	5.8
Fujitsu (Japan)	2.11	2.48	2.51	2.11	9.2	10.5
NTT (Japan)	1.99	1.89	1.84	1.75	4.0	4.6
Novartis (Switzerland)	-	-	-	-	10.1	-

Table 2: The World's Top 10 Spenders On R&D (£M) *- R&D as % of sales

Source: DTI 'The 1995 UK R&D Scoreboard'; Cookson (1997) Financial Time

(Number of Firms)

Country	Rank 1-50	Rank 51-100	Rank 101-150	Rank 151-200	Rank 1-200
USA	16	21	13	17	67
Japan	13	8	22	17	60
Germany	7	3	2	4	16
France	4	5	6	3	18
Switzerland	4	1	1	1	7
Canada	2	0	0	0	2
UK	1	6	3	2	12
Sweden	1	3	1	1	6
Netherlands	1	2	1	1	5
Italy	1	1	1	1	4
Finland	0	0	1	0	1
Belgium	0	0	1	0	1
Denmark	0	0	1	0	1

Table 3: International Ranking Of The Top 200 Companies By R&D Expenditure 1994

Source**:** Self Computations based on DTI - 'The 1995 UK R&D Scoreboard'.

Country	Production ($bn)	Consumption ($bn)	Production as % of GDP	Consumption as % of GDP
US	206.6	225.8	3.24	3.54
Japan	184.6	121.5	4.37	2.88
Germany	55.9	70.4	2.97	3.74
France	30.9	35.5	2.47	2.83
UK	28.4	35.6	3.04	3.81
South Korea	27.2	17.1	8.24	5.18
Italy	22.3	30.0	2.23	3.00
Singapore	17.3	9.4	31.40	17.06
Taiwan	15.9	9.3	7.34	4.30
Brazil	13.0	15.8	2.64	3.20

Table 4: The Consumption And Production Of IT (1994)

Adopted from Financial Time 7 April 1995 'World IT Production & Consumption'; Source: Office of Science and Technology

A. R&D In The IT Sector

It is likely that rapid growth of East Asian economies has been based on high utilisation of information technology and the expertise obtained from high IT based production and consumption activities (Table 4). At aggregate levels, the US and Japan still dominate the production and consumption data trends. However, some Asian Tigers have created a sufficient national production capacity for self-sustained production. For instance, IT production as a percentage of GDP in Singapore is 31.4, which is nearly ten times the figure recorded in the US; for consumption, the corresponding figure is almost 5 times the US level. Relatively higher rates of consumption of IT in other Asian Tigers including Taiwan and South Korea also signal that economies in East Asians may now spread innovations with accelerated pulses.

The powerhouse of innovative engineering products such as semi-conductors and high capacity fibre optic networks originated in the US, the dominant players being located in the Silicon Valley. The rapid growth in telecommunications and IT has produced a major force in the 1990s especially as Internet boosted communications for producers and consumers and search functions for both household and commercial activities. The development of internet communications quickens the exchange of information and consequently the diffusion of technological advance. Because IT can be applied to numerous manufacturing sectors, general trends in the development in IT sectors can be used as proxies for tracking technology movements in the world.

	85-90	91	92	93	94	95	96	91-96
Japan	61.33	67.15	70.61	70.92	70.63	69.26	67.80	69.39
Germany	11.84	8.92	7.34	6.95	6.51	6.60	6.29	7.10
France	7.17	5.85	5.58	5.43	5.00	4.95	4.92	5.29
UK	6.51	5.41	4.46	3.96	3.77	4.41	4.33	4.39
Canada	2.97	2.66	2.44	2.34	2.31	2.28	3.10	2.52
S. Korea	0.36	1.84	2.34	3.48	4.39	4.79	5.54	3.73
Netherlands	3.09	2.65	2.02	1.70	2.04	1.99	1.86	2.04
Others	6.73	5.52	5.21	5.22	5.35	5.72	6.16	5.54
Total	100	100	100	100	100	100	100	100

Table 5: Patent Distribution In The US IT Sector By Country (In %)
Source: ETRI Telecommunications Database 1997

Inspection of Table 5 reveals various degrees of patenting activity in the IT sector. The data excludes US domestic patent data as more than 50% of these are granted domestically which inevitably leads to biased over-representation. The key fact reflected in Table 5 is that IT patents are significantly concentrated among a few players. France, Germany, and the UK take a less significant share. South Korea just managed to get a small slice in US patents in the IT sector. These rankings are consistent to the figures in Tables 3 and 4. This implies that technology transfer in the global IT sector is dominated by the American expertise followed by Japanese producers. In terms of patent races, other OECD countries including Asian economies such as South Korea, Singapore and Taiwan, are playing catch-up strategies in IT and R&D. The picture of international involvement in R&D activities may be compared in data shown in Table 6. Thus present investment in R&D in science and technology may positively affect the future potential volume of successful innovations or granted patents. As with trends depicted in Table 5, expenditure in 1993 shows a positive association, with the number of patents awarded in the IT sectors, despite the fact that the composition of the R&D expenditure cannot be broken down to get an exact picture. However, in recent years, due to the rapid increase in liberalisation processes in telecommunication markets, the expenditure of R&D allocated to this sector yields a significant proportion of total R&D expenditure in science and technology. This proportion is significantly higher for the US and South Korea, which are 21.8 and 20.7 respectively. The latter largely concentrates on technology catch-up and reverse engineering in the telecommunication and information sectors as it obtains very limited number of patents in the IT sector (Table 5). However, Korean R&D seems to employ a more aggressive catch-up strategy than European countries in percentage terms.

	USA	Japan	UK	Germany	France	S. Korea*
(a) R&D Expenditure on Information & Telecommunications ($m)	40,139	20,756	1,879	3,270	3,040	2,034
(b) R&D Expenditure on Science & Technology ($m)	169,515	112,665	20,618	47,396	30,147	9,826
a/b	21.8	16.3	9.1	6.9	10.1	20.7
b/GNP	0.62	0.61	0.15	0.21	0.18	0.54

Table 6: International Comparison Of Science & Technology Activities (1993)
Note: *- figures for 1994. Source: ETRI

B. Human & Intangible Capital

At global level these western R&D-riched companies use large budgets to maintain competitiveness. This is consistent with Schumpeterian views on incentives to invest and Davies's (1979) study in which firms possessing innovations are characterised by scale economies[3]. However, a firm's advanced R&D knowledge contributes to its set of firm specific inimitable features. This helps to obtain long run competitive advantages (Porter, 1976). Research knowledge and expertise is regarded as a commercial secret and is protected by patents or licenses, which are difficult to diffuse to the whole of society. The pathway for this kind of knowledge transfer, however, relies on recruiting staff who possess special insights and knowledge from previous employments. As is evident in the differences in unemployment rates in the EU, Asia and the US, labour force mobility may be expected to differ. Higher unemployment rates restrict prospects for the labour force and this in turn lowers the labour turnover rates. Diffusion processes within an economy are quickened when higher labour mobility exists, as employees with specific knowledge or expertise are transferred to new working environments[4]. This fact needs to be supported by strong economic policies which require various types of labour skills which allow for rapid labour

[3] In industrial economics, R&D has crucial impact in the SCP paradigm. Schumpeter (1934) stressed the importance of large firms in exploring new technologies. This stimulated debates between Arrow (1962) and Demsetz (1969) over the Arrow-Schumpeter hypothesis that monopoly structures and bigness provide superior incentives to innovate than competitive structures.

[4] Similarly, in Japan, life-time employment systems have been practised by Japanese companies historically. Recently, some major Japanese enterprises such as Panasonic, announced the ending of this employment culture. Some entrepreneurs are afraid that this may lead to leakage of company confidential expertise. On the other hand, industrial experts think that this helps transfer crucial 'soft' technological knowledge.

turnover. Such labour movement in the long term increases the possibility of achieving rising productivity and overall increases in living standards.

In national terms, effective diffusion leads to economy-wide increases in well-being which can be observed in rising general living standards and other economic indicators such as GNP/ GDP per capita, industrial output aggregates and, even from employment data. Unemployment data for Asian economies may represent a truer reflection of growth and diffusion as social welfare benefits are meagre compared with western economies, such a the EU. Therefore, widespread technological usage may create higher unemployment rates in EU countries, than in healthy Asian economies. The substantial link between diffusion and other economic factors excludes the effect of extraordinary cyclical or unexpected events such as the 1997 currency crisis in Asia. For instance, the Korean currency crisis led to serious debt problems across the whole nation and the closure of large corporations. The credit levels of existing companies were constrained which significantly hindered reinvestment, especially for substantial projects like R&D. Eventually, their capabilities to foster technical advance and diffusion will be very constrained unless debt levels fall.

- *R&D Expenditure*
- *Know-how*
- *Industrial Patterns & Design*
- *Patents & Licences*
- *Artistic Creations, Copyright*
- *Right To Receive Royalty Payment*
- *Training & Other Investment In Human Resources*
- *Market Share*
- *Product Certification*
- *Customer Lists, Subscriber Lists & Lists of Potential Customers*
- *Product Brand & Service Brands*
- *Software & Similar Products*

Table 7: Components Of Immaterial Investment (OECD Literature)
Source: European Commission (1997)

To assist the occurrence of wide spread development, not only scientific product/ machinery knowledge ('hard' technology) should be considered but other non-materiel knowledge or, intangible assets such as marketing management, advertising, staff training ('soft' technology) are equally significant. According to the OECD, R&D expenditure is only one of the components of immaterial investments (See Table 7).

Krugman (1994) argues that the high growth rates in Asia rely on investment in human and physical capital and other resources. Krugman uses a very clean-cut separation for contributions originating from increasing human and physical capital and technical change. He does not believe that the extensive growth in East Asia was driven by technological progresses alone. The key significance of investment in human capital can be seen in Drysdale and Huang's (1997) study. This study emphasises the role of technology catch-up (i.e. the rise of productivity) among East Asian economies as an extensive growth process in recent decades. Moreover, Drysdale and Huang (ibid.) assert that higher than average growth rates experienced in East Asian economies including Hong Kong, Taiwan, and South Korea is mainly attributable to the success of technological progress, particularly the rise of productivity. However, they indicate that the percentage contributions by human inputs was also very high. (Table 8).

(% per annum)

East Asian Countries	**Output Growth**	**Contribution by Capital**	**Contribution by Labour**
NICs			
Hong Kong	9.0	2.8	3.1
South Korea	7.4	2.9	2.4
Taiwan	8.6	2.6	3.1
Singapore	7.7	3.9	3.0
ASEANs			
Indonesia	6.7	2.6	2.0
Malaysia	6.0	3.6	2.9
Philippines	4.9	2.4	2.3
Thailand	5.8	1.7	2.4
Other:			
Japan	6.8	3.7	0.8
China	5.5	2.9	2.2

Table 8: Growth In East Asian Economies By Contribution During 1950-90
Source: Drysdale and Huang's (1997)

The contribution of human capital creates a relatively greater impact in newly industrialising countries (NICs), than in those ASEAN*4*. Human knowledge and expertise are important aspects throughout general technological progress, which is demonstrated by the significant shift towards intangible asset investment in OECD countries. This usually serves as a proxy for the global trends. Inspection of the data in Table 9 indicates that, on average, there has been a 42.31% rise in the usage of intangible assets. On the contrary, tangible investment suffered a 14.77% decrease.

Country	*Tangible* 1974	*Tangible* 1984	Intangible 1974	Intangible 1984
United States	*14.2*	*13.2*	4.4	6.2
Japan	*26.9*	*22.9*	2.4	3.5
France	*16.8*	*13.4*	2.3	3.1
Germany	*15.0*	*13.8*	2.4	3.6
Italy	*18.1*	*14.7*	1.0	1.9
Netherlands	*16.1*	*13.5*	2.6	3.7
UK	*16.3*	*13.5*	3.1	3.8
Average	*17.6*	*15.0*	2.6	3.7

Table 9: Investment In Tangible And Intangible Assets In Selected Countries (% Of GDP)
Source: European Commission (1997)

Given the rising importance of intangible assets in global and national terms, the involvement of human capital has started to gain more momentum. Some economists particularly stress human aspects of technological progress such as the importance of entrepreneurship in Schmitze's (1989) study and human capital/ knowledge investment in Romer's (1986) study.

	Labour	Capital	Real GDP
Australia	0.6	2.1	2.5
North America	0.9	2.8	2.7
EU12	0.2	1.3	2.2
Japan	-0.2	3.3	2.6
NICs	0.9	6.3	6.3

ASEAN	2.2	6.8	6.8
China	2.4	9.3	8.9
South Asia	2.4	7.1	5.2
Latin America	2.2	1.2	3.6
Central & Eastern Europe	0.9	6.0	6.0
Former Soviet Union	0.0	4.4	4.4
Rest of the World	2.4	2.5	2.5

Table 10: Projections Of Annual Average Growth Rates Of Macro-Economic Variables (1992-2005)

Source: Hertel et al (1995), World Bank (1995) and Yang and Zhong (1996)

Projections of growth rates for labour and capital in Asian economies also show relatively higher percentages compared to other dominant economies such as the EU and the US (Table 10). These data indicate that better management of human capital and other physical capital may help the Asian economies to obtain higher productivity growth and technological progress in relative terms

C. Trade And Spillovers

International trade development has a great impact in shaping the international movement of technology advance. With increasing liberalisation of trade within Asia in recent decades, the diffusion of technical advance into Asian economies has become more rapid. The rising indirect influences of foreign R&D in Asian economies via trade flows is depicted in Table 11.

From	To	Japan	China	ASEAN	NICs	South Asia	ANZ
EU	Total Trade	0.74	3.68	2.05	1.98	1.25	1.39
	Manufactures	0.69	3.47	1.79	1.84	1.24	1.37
	Machinery	0.83	3.95	1.63	1.52	1.20	1.68
	Transport equipment	0.46	5.24	2.21	2.16	2.41	1.34
	Chemicals	0.84	-0.36	1.41	1.21	1.09	1.30
US	Total Trade	0.63	1.86	2.03	1.32	0.44	0.96
	Manufactures	0.75	1.82	1.84	1.37	0.55	0.89
	Machinery	0.55	2.48	1.84	1.42	1.42	1.07
	Transport equipment	2.31	4.51	1.49	1.64	4.15	0.31
	Chemicals	0.39	-0.30	1.67	0.99	-1.30	0.70
Japan	Total Trade	-	3.28	1.95	1.41	0.34	1.30
	Manufactures	-	3.32	1.99	1.40	0.38	1.25
	Machinery	-	3.54	1.95	1.40	0.25	0.84
	Transport equipment	-	5.95	2.24	1.75	0.00	2.07
	Chemicals	-	0.55	1.53	1.03	1.15	0.80

Table 11: The Growth Of Export To Asian Economies By Sectors 1991-94 (In %)

Source: Langhammer (1998)/ UN, Monthly Bulletin of Statistics-Various Issues

If the international trade is divided according to a zoning system or based on the so-called trading blocs, the rapid increase in inter-bloc international trade represents an increase in technological diffusion. The movement of trade in different countries/ sectors proxies the flow of foreign R&D. Table 12 shows the bilateral trade ratios between different pairings of trading blocs. Rising ratios indicate the increased importance of each regional trading zone to others. Figures relating to developing Asia

(Dev. As) have shown increasing convergency with the EU and the US in overall trade, manufactures, and machinery and transport equipment.

	Total Trade				Trade in Manufactures				Trade in machinery & transport equipment			
	Dev. As/Eu	Jp/ Eu	Dev. As/ Us	Jp/ Us	Dev. As/Eu	Jp/ Eu	Dev. As/ Us	Jp/ Us	Dev. As/Eu	Jp/ Eu	Dev. As/ Us	Jp/ Us
1980	0.35	0.11	0.40	0.39	0.33	0.17	0.40	0.22	0.44	0.10	0.27	0.15
1990	0.48	0.29	0.47	0.39	0.46	0.29	0.39	0.29	0.49	0.24	0.36	0.23
1991	0.49	0.27	0.51	0.39	0.46	0.27	0.43	0.29	0.51	0.22	0.40	0.23
1992	0.53	0.25	0.50	0.38	0.51	0.25	0.43	0.28	0.57	0.19	0.42	0.23
1993	0.63	0.29	0.52	0.36	0.62	0.29	0.47	0.26	0.68	0.24	0.49	0.20
1994	0.67	0.33	0.53	0.35	0.68	0.33	0.46	0.27	0.76	0.27	0.47	0.23

Table 12: Bilateral Export Market Convergency Ratios In Trade (1980-94)
Source: Langhammer (1998)/ UN, Monthly Bulletin of Statistics
Note: Dev. As- Developing Asia; Eu- European Union; Jp- Japan; Us- United States

From a regional perspective, intra-regional trade may represent a more intensified exchange of expertise and R&D products which is due to the affinity of cultural, historical trade links and geographical proximity. The best example is the European Union, within which there exits strong institutional guidelines for competition and harmonisation which facilitates EU-wide trade development.. Similarly, NAFTA and APEC are actively promoting trade within the Northern America and Asia-Pacific regions respectively. However, the former established a free trade zone. While APEC utilises a non-binding non-discriminating unilateral liberalisation approach towards trade and promotes the virtues of open regionalism. By contrast, EU trade stimulates increased trade flows within member states. The inward EU integration by establishing a custom unions technically violates the WTO most favourable nations principles. This reinforces regional protectionist pressures and reduces the constructive role of liberalisation of global trade. In aggregate terms, the trade regime of multi-lateral liberalisation proposed by the WTO increases the trade flows between participating countries, thus increasing the diffusion of R&D products.

	Effect of 1% increase in foreign R&D stock on total factor productivity (TFP)*
Belgium	0.26
Ireland	0.16
US	0.03
Japan	0.025

Table 13: The Effect Of Foreign R&D Stocks (1990)
Source: Coe and Helpman (1995)
Note: *- refers to productivity growth in output which is not resulted from the extra labour or capital

The resulting benefits of any new innovation may go to private firms. However, there are spillover effects which deters ambitious decision makers promoting R&D[5].

[5] According to Coe (ibid.) from a study of 22 industrial economies between 1971 and 1990, the impact of domestic increase in R&D on TFP is more significant for large countries. A 1% increase in G7 countries R&D provides 0.23 increase in TFP. The corresponding increases for the other 15 smaller countries is only 0.08%.

Inspection of Table 13 implies that spillover benefits obtained by small economies (Belgium and Ireland) are far greater than those for large industrialised economies (the US and Japan). Apart from Japan, most Asian economies are small developing nations which also are in favourable positions to enjoy spillover externalities from dominant market leaders. For instance, Singapore improves its TFP by 0.22% for every 1% increase in the R&D stock in the US. While the corresponding average improvement achieved in other larger OECD countries is about 0.04% (Coe, ibid). This is why most Asian economies, even the more developed Asian Tiger economies, have been active in the technology catch-up process, rather than maintaining in high-profile patent races. Positive externalities deter smaller economies from doing more home-grown R&D projects. The success of this form of diffusion creating rising productivity (foreign R&D) results from high levels of trade liberalisation.[6]

IV. A New Regime

The use of national initiatives targeted at technological advance has been a highly controversial topic. The choice of national technology systems undoubtedly affects the international flow of technology advance. Nelson (1995) discusses national systems of technical innovation in detail by using a comparative analysis consisting of case studies in 15 countries, which illuminate the institutions and mechanisms behind the various structures of national R&D regimes. Chapman and Humphrys (1987) argue that R&D is the significant element for rejuvenating existing industries, such as heavy industry (iron and steel). Hayter (1993) stresses the paradoxical effects of R&D on nations. Thus it is costly to carry out R&D. Even if an innovation becomes successful, it may never turn out to be viable in commercial terms. Moreover, the complicated issues surrounding R&D investment in every nation are subject to decision making processes and external market forces. In fact the optimal role for government to pay in R&D strategy is a difficult task. On one side, politicians would like to see government giving tax credits or other forms of subsidies to strengthen R&D and consequently raising productivity and growth. While anti-interventionists or free market economists prefer private enterprise to establish R&D momentum.

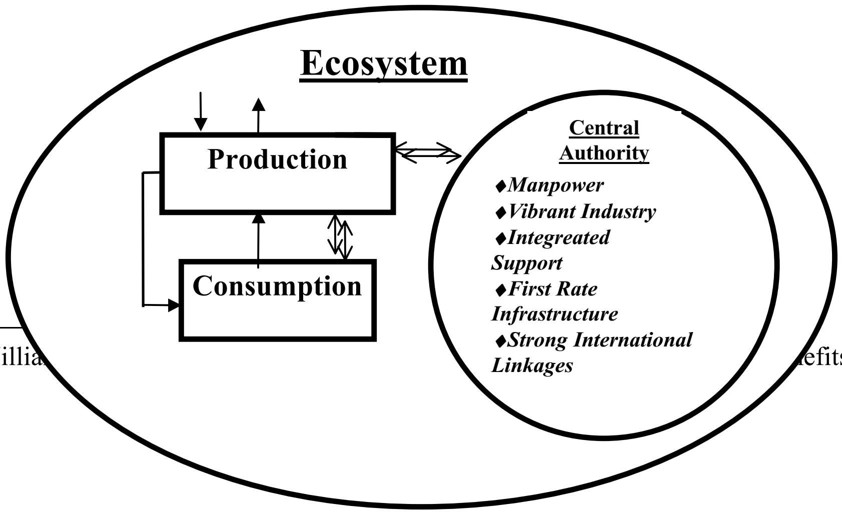
Given that big firms invest huge sums in R&D, approximately on a world average at about 4.5% of sales, it is obvious that large firms pay more attention to innovation. However, spending more does not mean that greater success can be automatically achieved. It is a matter of R&D productivity. To enhance this productivity, human inputs, operational linkages and strategic management are important. The share of growth contributed by human and physical factors to the overall growth of East Asian economies is shown in Table 8.

The technological diffusion process is also affected by the type of R&D paradigm employed. At the turn of 20th century, the influential role of UK innovative R&D was surpassed by the US and Germany, which are now often regarded as pioneers of professionalised R&D. This professionalism was further amplified by the Japanese industrial science and innovation since 1945. In recent decades, R&D investment has passed through several phases of transition. The most dominant R&D reinforcement is

[6] Take Belgium as an example, imports represent almost 90% of GNP. (Economist, 1995). The highly liberalised trade strategy brought Belgium beneficial gains from foreign imports and foreign technology advances.

the shift from the Fordist techno-economic paradigm to the IT techno-economic paradigm. The major problem involved in the former is the lack of feedback and integrative mechanisms from its linear application of innovation. Since mid 1970s' due to energy crises, severe recessions, and greater intensity of processes of differentiations, loopy systems emerged. The Japanese developed flexible production systems with integrated loopy models for innovative technological advancements. The concept of 'reverse engineering' and continuous upgrading practices (*Kaizen*) were incorporated from mid 1970s'. This integrated approach introduces new boost factor into the depth and spread of diffusion, and also the comprehensive nature of expertise created. With the tremendous advances in information technology such as the Internet and digital telecommunications technologies, the integrated approach can be further intensified. However, this means that the linkages between system elements are now more interlocking and multi-hinged. To uncover and explore the cream of technological change and the associated diffusion process, a dynamic approach is required. At the level of the firm, strategic thinking should be comprehensively integrated, like a spider's web which allows information to be collected, analysed and diffused to suit the need of various functional parts (U-form firms) or different product groupings (M-form firms)[7].

Nation-wide diffusion may involve more functional activities from various authorities. Such activity gives involved agents more relevant and clear information. Referring back to Table 4, Singapore has the highest IT consumption per capita. This signals a network of efficient communication infrastructures within the economy which facilitates the knowledge diffusion in line with integrated loopy systems under the IT techno-economic paradigm. In 1999, the Malaysian government launched a £8.2bn Silicon Valley type called Multimedia Super Corridor (MSC) to transform Malaysia into a knowledge-based economy. The Cyberjaya, intelligent city at the centre of the MSC, which aims to establish a full wired cyber city, is conceived as a giant engine of growth for a new socio-economic regime in Malaysia since the onset of the recent Asian crisis (McNulty, 1999). The MSC infra-structure project will promote pioneering high-tech research and development to replace the current manufacturing-based economy activities. Moreover, following the success of the Singaporean government project, Singapore One, Hong Kong also announced its plan to build a HK$13bn infrastructural project, namely "cyberport", to catch-up with rivals attracting high-tech companies for promoting as an international information service hub (Montagnon, 1999).



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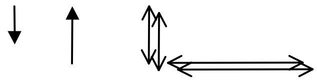

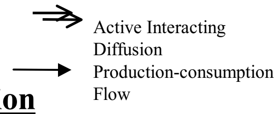

Diagram 2: A Ecosystem Regime For Technological Diffusion

The proposed regime is largely based on key concepts and some crucial factors identified earlier. Actual implementation may require more adjustments and fine-tuning. However, Diagram 2 displays the philosophy behind the regime construction. The system consists of 3 major elements, namely; the classical production-consumption flow system, the mechanism of central authority and the balancing forces of the ecosystem.

The key structure of this system falls on the role of the central authority. Thus authority has the function to organise resources and allows effective and transparent information changes to match with the paradigms used in manufacturing. The construction of this authority could follow the Asian Tiger Economies example, which enjoys closer proximity to cultural and contextual practices. The illustrative example chosen here is that of the Singaporean National Science and Technology Board's model. Its achievements have been widely perceived as a national success[8]. The key factors are shown inside the circle in Diagram 2. These factors are major initiatives aiming to establish national pride in widespread R&D education and innovation to advance the quality of life.

The use of an ecosystem-typed format is based on the ultimate aim of R&D investment which is supposed to link closely to the improvement in all well-being of human life from a societal point of view. The existence of ecosystems requires self-balancing forces to achieve vital sustainability. Innovation and diffusion eventually results in new products. This means they also generate new problems and new economic wastes. This may upset the balance of the ecosystem and put extra burdens on future generations, if environmental concerns are not seriously handled. Our quality of life moves on as new innovated products are produced. However, our life quality will not be sustainable if innovation consumes too much from the natural environment, and generates too few positive influences for the benefit of the environment. This sustainability philosophy is similar to the Intelligent Manufacturing System (IMS) programme proposed by Japan few years ago[9].

V. Conclusions

Improvement of technology applications in manufacturing and business is important to any economies in the world. Technology advance can be fundamentally achieved via R&D strategies or direct purchase of foreign capital goods and indirectly obtained through international trade. New ways of considering R&D in National Economic

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two types of organisational firm, with particular emphases on the optimal organisation structures.

[8] Detailed implementation and polices can be found in the web site http://www.nstb.gov.sg/infrastructure/knowledge.html.

[9] A recent discussion of the IMS programme can be seen from Toyama (1997).

Systems are vital for progress to be maintained in global terms. The recommendation here is that the eco-system type model may possess a sufficiently all-encompassing elements to benefit most growing economies. The key dominant role of R&D in promoting growth is recognised but should be directed by national agencies which can adopt a facilitating role and harmonise socio-economic with environmental issues and concerns.

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