Catch Up in Integrated Circuits Production: Malaysia Compared to Korea and Taiwan

Rajah Rasiah

*Abstract***:** Taking account of existing theories but screening them with the purpose of stimulating competitiveness of national firms the lecture identifies the coordinates of industrial policy that are relevant for driving technological catch up. Like Malaysia, the governments of Korea and Taiwan used industrial policy as the spearhead of technological catch up and rapid growth. However, unlike Korea and Taiwan, which have become high income economies, Malaysia has remained stuck in the middle income group. This lecture dissects the integrated circuits industry, which has been promoted extensively by all three countries, to capture regulatory differences to explain the differential performance. Instead of reinventing the wheel, the lecture will build on the successful catch up experiences of integrated circuits firms from Korea and Taiwan. The lecture offers evidence to argue that two critical reasons explain why national IC firms in Korea and Taiwan were successful in reaching the technology frontier while those in Malaysia have languished far behind. First, is the lack of a governance mechanism at the national level to vet *ex ante*, monitor and to appraise *ex post* government funded initiatives. Second, national IC firms in Korea and Taiwan enjoyed significant support from rapid expansion in human capital – generated from both domestic institutes, as well as, the diaspora endowed with tacit and experiential knowledge in R&D, IC design, fabrication and market networks. Malaysia has faced severe deficits in both categories of human capital.

Keywords Innovation, regulatory framework, technological catch up, competitiveness, integrated circuits

1. Introduction

Development economists have sought to understand the drivers each time latecomer national industrial firms leapfrogged to the front or reached the frontier of particular industries. Instead of the neoclassical focus on avoiding price distortions or other forms of interventions evolutionary economists have attempted to cast their lenses as wide as possible to map and capture the drivers, including the complex web of interactions between agents, institutions and *meso* organizations. Consistent with the Schumpeterian productive rents (Schumpeter, 1934), interventions are essential to support learning and innovation in risky and uncertain activities to attract investments and stimulate support technological catch up in industries characterized by scale and high knowledge intensities (public goods) (see also Arrow, 1962; Khan, 1989). Companies in such activities may crumble rather than compete if exposed early to liberal currents. Johnson (1982) had documented that Japan's Ministry of International Trade and Industry (MITI) recognized this fact when promoting heavy and knowledge-intensive industries. Despite facing enormous pressure to liberalize from national economists and policymakers of trading nations such as the United States and France, the competition policy that MITI pursued from the late 1950s sought to build competitiveness by ensuring that it created the conditions for national firms to evolve the capabilities to compete. Although anti-trust regulations evolved strongly in the United States, the government had on a number of occasions relaxed it when it was viewed as pertinent to protect American firms against global competition. The relaxation of anti-trust regulations in support of American IC firms in 1989 to compete with Japanese firms by the Reagan administration is one occasion. Yet, competition was pertinent in ensuring that American firms in critical industries invested in R&D to stay at the frontier (see Scherer, 1992).[1]

However, the high incidence of government failures across the world raises the observation that industrial policy can only be a necessary but not a sufficient condition for technological catch up, and with that, rapid growth and structural change. The developmental state literature is now divided over how governments can be made effective. On the one hand, Mustaq (1989) and Evan's (1995) argue that the government should enjoy the autonomy from interest groups to formulate and coordinate successful catch up. On the other hand, Doner (2009) argues that there should be productive veto groups to force governments to formulate and coordinate coherent and cogent policies to drive catch ups. Within national capital, ownership did not matter in South Korea as state owned Pohang Steel Company (POSCO) and chaebol structured Samsung Electronics reached the technological frontier in steel and electronics goods respectively (see Amsden, 1989; Kim, 1997). The evolutionary argument would simply leave it inductively to the specificity of the industry, time and space (see Nelson, 2008).

Any attempt to construct a regulatory framework to stimulate technological catch up in a scale- or a knowledge-based industry, thus, requires a careful explication of the conditions that are

[1] Kodak responded positively to competition from Fuji while it was too late for the Radio Company of America (RCA) to counter competition from Toshiba (see Scherer, 1992).

essential to make it work. This lecture examines the leading arguments on technological catch up. It then compares the performance of the integrated circuits industries of Korea, Taiwan and Malaysia. The lecture subsequently analyzes the policy frameworks implemented by government in the three countries. The final section finishes with the conclusions and policy implications.

2. Theoretical Considerations

Arguments on the interventionist state in latecomer industrialization contesting neoliberal advocacy of leaving growth and structural change to market forces has a long history. Britain's ascendance as the factory of the world by the mid-18th century had early beginnings with the introduction of export taxes on animal hides by Henry the 7th in 1485 (see Reinert, 2007: 79). The role of the state in promoting increasing returns activities dominated early promotion of industry (see Smith, 1776; Hamilton, 1791; List, 1885; Gershenkron, 1962; Kaldor, 1967). The subsequent articulation of this argument augmented history with the paths taken by Japan (Johnson, 1982), Korea (Amsden, 1989) and Taiwan (Fransman, 1986). Despite the common objective the different vantage points of these approaches led to their classification as heterodox theories. Evans (1995) attempted to identify the key pillars of the developmental state while mainstream economists began to accede to the mounting evidence of market failures by introducing new institutional economics (see Coase, 1937; Williamson, 1975; North, 1990) and endogenous growth theory (see Romer, 1986; Lucas, 1988). While developmental state exponents have continued to redefine their framework with empirical evidence, new growth modellists have limited their work to an academic exercise where scale economies are absorbed in the theorizing but are not encouraged as a policy prescription by claiming that government failures are more serious than market failures. The new institutional economists accommodate problems of markets but identify markets as the superior institution that should leave only the problematic space to other institutions.

The significance of industrialization in driving increasing returns on economic activities was first noted by Smith (1776). Young (1928) subsequently articulated lucidly the economic synergies that are unleashed from the differentiation and division of labour that industry provides. Kaldor (1957, 1967) and Cripps and Tarling (1973) advanced the cumulative causation effects argument to demonstrate the benefits of promoting industrialization. Kaldor (1957, 1967) used the Verdoorn relationship to argue that manufacturing possessed increasing returns properties and hence enjoyed the greatest potential for supporting rapid economic growth.[2] Using two

[2] Kaldor (1957, 1967) focused on the differentiating properties associated with manufacturing, which he argued also enjoyed strong complementarities and structural inter-dependence to stimulate other industries.

econometric equations Kaldor demonstrated that manufacturing enjoyed a positive and strongest elasticity of change with GDP. Although statistical problems with Kaldor's growth equations have long been acknowledged (see Rowthorn, 1979),[3] the increasing returns properties of manufacturing has remained the key drivers of rapid growth and structural change in heterodox arguments (see Singh, 1989).[4] Cripps and Tarling (1973) used trade effects to make the same point. Recognizing that market failures can seriously hamper technological catch up initiatives, heterodox economists argued for interventions to augment or substitute for relative prices.

The increasing returns argument is strongly demonstrated in R&D activities. Figure 1 shows the characteristic features of IC production where participation in R&D is highly costly but the public goods characteristics of it is considerable. In the process of generating knowledge a significant amount of it will not translate into profits for the owners of the research. Only the products or services that come out from what is defined through the property rights regime – i.e. patents, designs, layouts and trade secrets can be appropriated through commercialization by the owners (i.e., t1, t2 and t3 in the blue boxes). However, research often produces stocks of knowledge that either directly or indirectly synergizes the production of other products and services that cannot be appropriated by the owners of the research laboratory. Other actors often appropriate the benefits instead (t-7…t3 in the purple boxes). Also, first movers often appropriate less economic synergies than what their innovations generate leaving considerable economic synergies to latecomers. Also, the spillover potential of R&D labs words are generally higher than what is actually appropriated. This is the public good feature of knowledge as its contribution cannot be confined just to the owner. Given the enabler properties of ICs, its capacity to generate such synergizing knowledge will be higher than most other products and services. Clearly, research here produces public returns to exceed private returns (see Arrow, 1962). Hence, government intervention will be an important driver of technological catch up in IC production.

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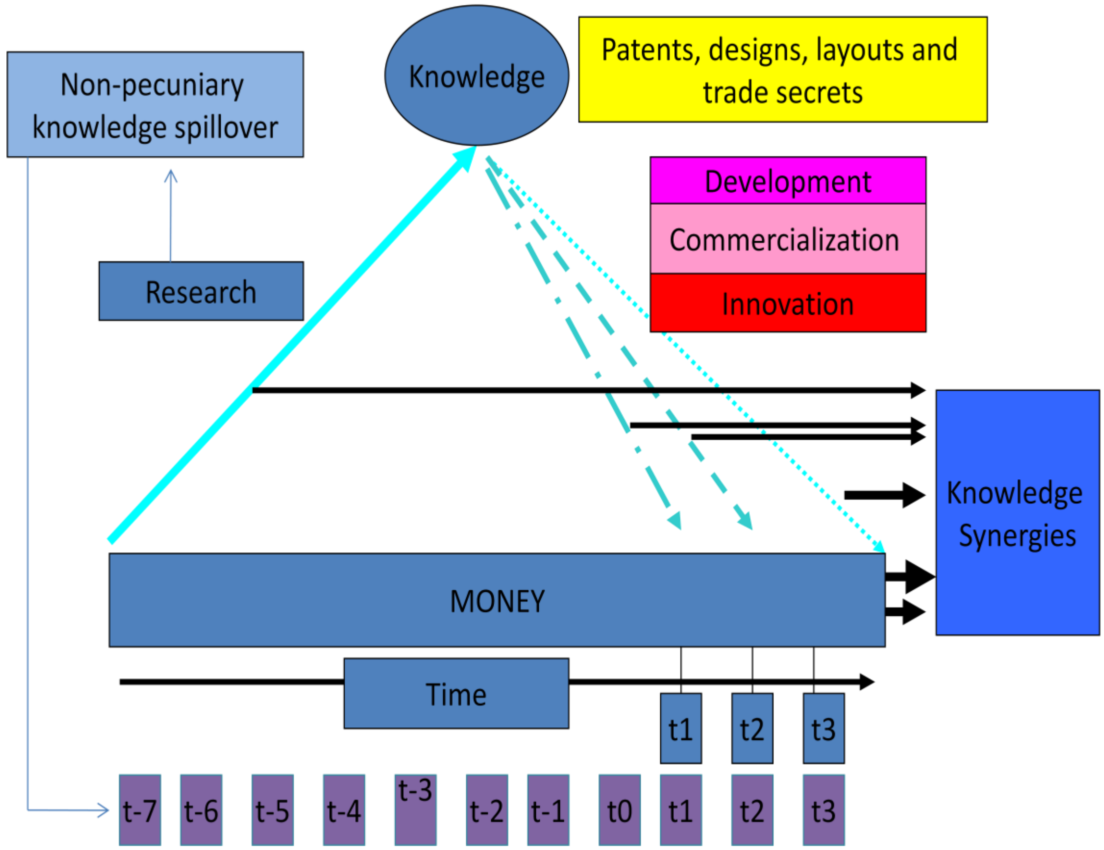
[3] Rowthorn's (1979) main contention was on the formulation of Kaldor's equations rather than his economic argument on increasing returns.

[4] Singh (1989) discussed the reasons why the unfinished industrialization process in the third world should continue.

Figure 1: Knowledge Synergies Associated with Research



Source: Author.

Economic historians tracing successful industrial policy thrusts have been able to establish a number of drivers that are paramount for achieving rapid growth and structural change. Accounts showing government's role in supporting industrialization can be traced to Hamilton (1791), List (1885), Gerschenkron (1962), Chang (2003) and Reinert (2007). Whereas Hamilton (1791) and List (1885) provided the argument to support industrial policy through protection and a strong emphasis on technological catch up, Gerschenkron (1962), Chang (2003) and Reinert (2007) provided a synthesis of historical evidence to argue that for industrial policy to direct investment into increasing returns activities, which is necessary to stimulate rapid growth, structural change and the alleviation of poverty.

Exponents of the developmental state theory focused on institutional arrangements to address collective action problems and scale economies to drive catch up in heavy and high tech industries (e.g. Johnson, 1982). The pervasive nature of the role of the Ministry of International Trade and Industry (MITI) from the late 1950s in guiding competitiveness is a good example of how competition became the consequence rather than the cause of industrial catch up with nascent industries where the focus was on importing technologies and building capabilities. Johnson (1982: 236) stated the following:

> .. the late 1950's MITI system of nurturing (*ikusei*) a new industry (for example, petrochemicals) included the following measures: first an investigation was made and a basic policy statement was drafted within the ministry on the need for the industry and on its prospects – an example is the Petrochemical Nurturing Policy adopted by a MITI ministerial conference on July 1 1955. Second, foreign currency allocations were authorized by MITI and funding was provided for the industry by the Development Bank. Third, licenses were granted for the import of foreign technology … Fourth, the nascent industry was designated as 'strategic' in order to give it special and accelerated depreciation on investment. Fifth, it was provided with improved land on which to build its installations, either free of charge or at nominal cost….Sixth, the industry was given key tax breaks … Seventh, MITI created an 'administrative guidance cartel' to regulate competition and coordinate investment among the firms in the industry.

Importantly, MITI vetted *ex ante*, monitored and appraised *ex post* to evolve the regulatory body's capabilities (Johnson, 1982). Since the role of the government has only been a necessary but not a sufficient condition for successful industrial transformation to high value added activities, developmental state theorists have tried to establish a framework to explain when government intervention will work. Screening a wide range of issues within industrial policy, Johnson (1982) set out to examine the miraculous role played by Japan's Ministry of International Trade and Industry to promote chemical and heavy industrialization. The tussle between officials of MITI and the foreign ministry left coordination difficult as external pressures from the United States and Europeans to liberalize became increasingly untenable as Japan needed cordial relations with them to sustain its export-oriented strategy (see Johnson, 1982). Nevertheless, despite all the problems MITI did manage to enforce the conditions essential to drive catch up in the industry. The regulatory framework used by government in Korea and Taiwan was in many cases similar but in other cases different from that of Japan.

Amsden (1989) added the use of export quotas for performance standards in the successful push towards heavy industrialization in Korea. Evans (1995) sought to establish the critical pillars necessary to stimulate industrialization by attempting different formulations of state capacities. Strong autonomous political regimes backed by a sound bureaucracy were, argued by Evans, as essential to make industrial policy work. Fransman (1985) and later Wade (1990) provided evidence of government intervention to promote local firms without comprising on efficiency of dependent industries. McKendrick, Haggard and Doner (2000) discussed at length the importance of government in solving collective action problems that arise from critical upgrading activities such as training and R&D. Doner (2009) advanced the developmental state theory further by articulating the role of veto players in ensuring the strengthening of effective institutional capacities by ameliorating vulnerabilities arising from resource scarcity, external threats and popular pressures.

Heterodox and the developmental state theories can be further strengthened by integrating the inductive approach that takes account of specificities over time and space typical of evolutionary theorizing. There is a need here to go beyond the arguments of the new institutional economists such as Coase (1937), Williamson (1975) and North (1990) as they are essentially extensions of the market failure argument that leaves markets as the superior allocator and coordinator of transactions. The works of evolutionary economists, who attempt to capture the drivers of economic actions by focusing on all critical institutions, becomes pertinent here (see Nelson and Winter, 1982; Malerba, Orsenigo, Nelson and Winter, 2008). Nelson (2008) calls it appreciative theorizing to distinguish it from formal theorizing. There are a series of lectures published on technological catch up, including leapfrogging (e.g. Samsung over Hitachi in DRAMs and Sony in stereo sets) where evolutionary theorists attempt to explain each different success stories by identifying their critical drivers. The export performance quota demonstrated by Amsden (1989) as the prime monitoring vehicle used by the Korean government is easy to manage but as Doner argues gives little clue on the actual instruments of upgrading. Since effective institutional change is central to understanding evolutionary postulations of technological catch up it is here that the fundamental differences in successes and failures of government policy can be understood.

3. IC Production Experiences Compared

National markets drove the emergence of IC production in the United States,[5] while foreign MNC-driven export markets started IC production in Korea and Taiwan in the 1960s and Malaysia in the 1970s. While domestic demand from consumer and industrial electronics firms played an important role in the emergence of national IC firms, export demand remained the key driver of production of national IC firms in Taiwan and Malaysia. Fairchild was the first private firm to manufacture ICs. Despite demonstrating considerable exports since 1972, IC production has largely been limited to the low end stages of assembly and testing in Malaysia. This section presents the trade performance of ICs at the national level, value chain segment specialization, product specialization, patent take up in the United States and the revenues earned by the top national IC firms in Korea, Taiwan and Malaysia.

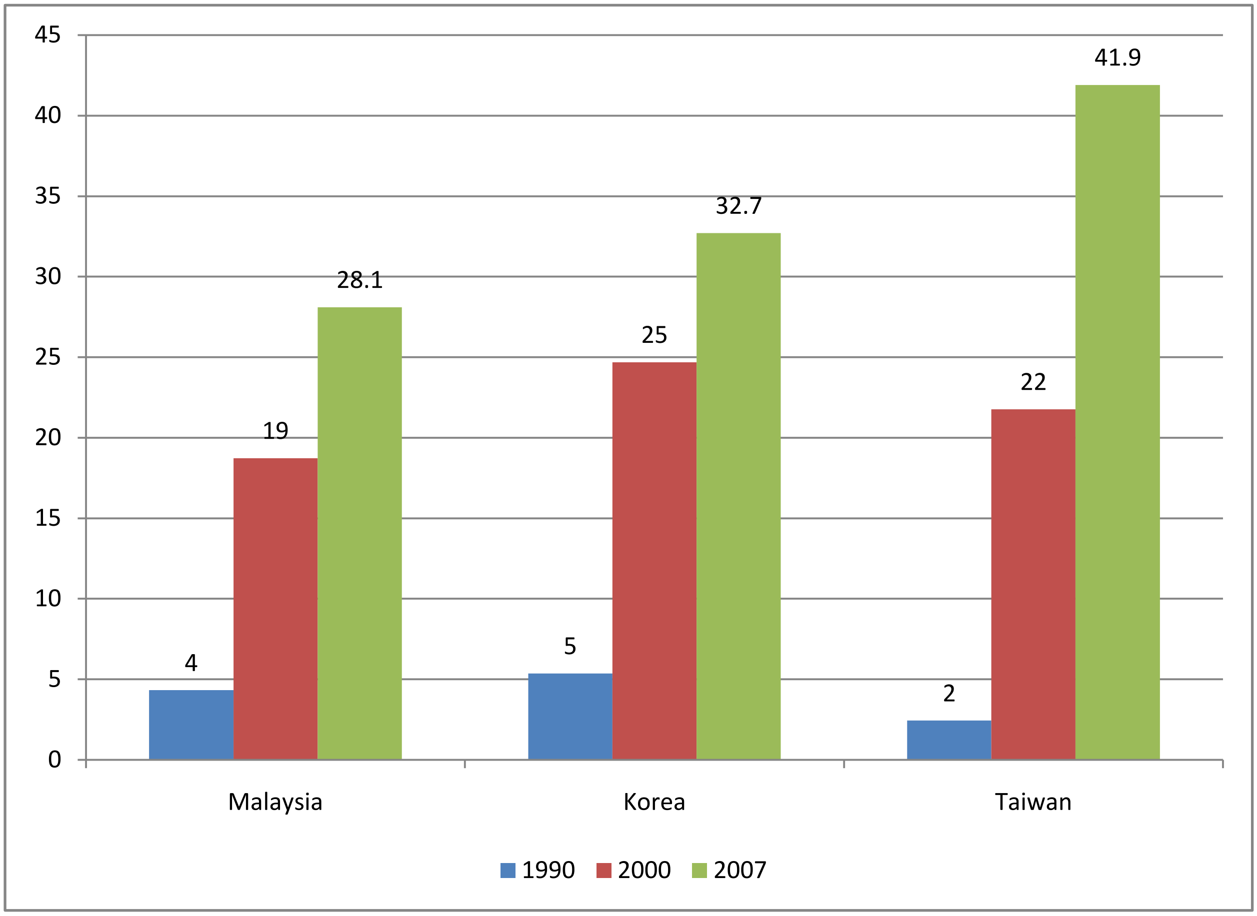
[5] The initial driver of innovation in IC manufacturing was the government in the United States, whose focus on radar precision monitoring and control for the military to fight the German army in the second world war triggered R&D into electronic control products (see Malerba, Nelson, Orsenigo, and Winter, 2008).

Trade Performance

Figures 2, 3 and 4 show exports, imports and trade balance of ICs of Malaysia, Korea and Taiwan over the period of 1990-2008. It can be seen that Taiwan has arguably enjoyed the fastest growth in exports but the slowest growth in imports, resulting in the most impressive improvements in the trade balance over the period. Indeed, Taiwan also enjoyed a higher trade balance than Korea in 2008. Since the trade data covers the aggregate figures of the nations as a whole, Taiwan's overall performance can be viewed as the most stellar.

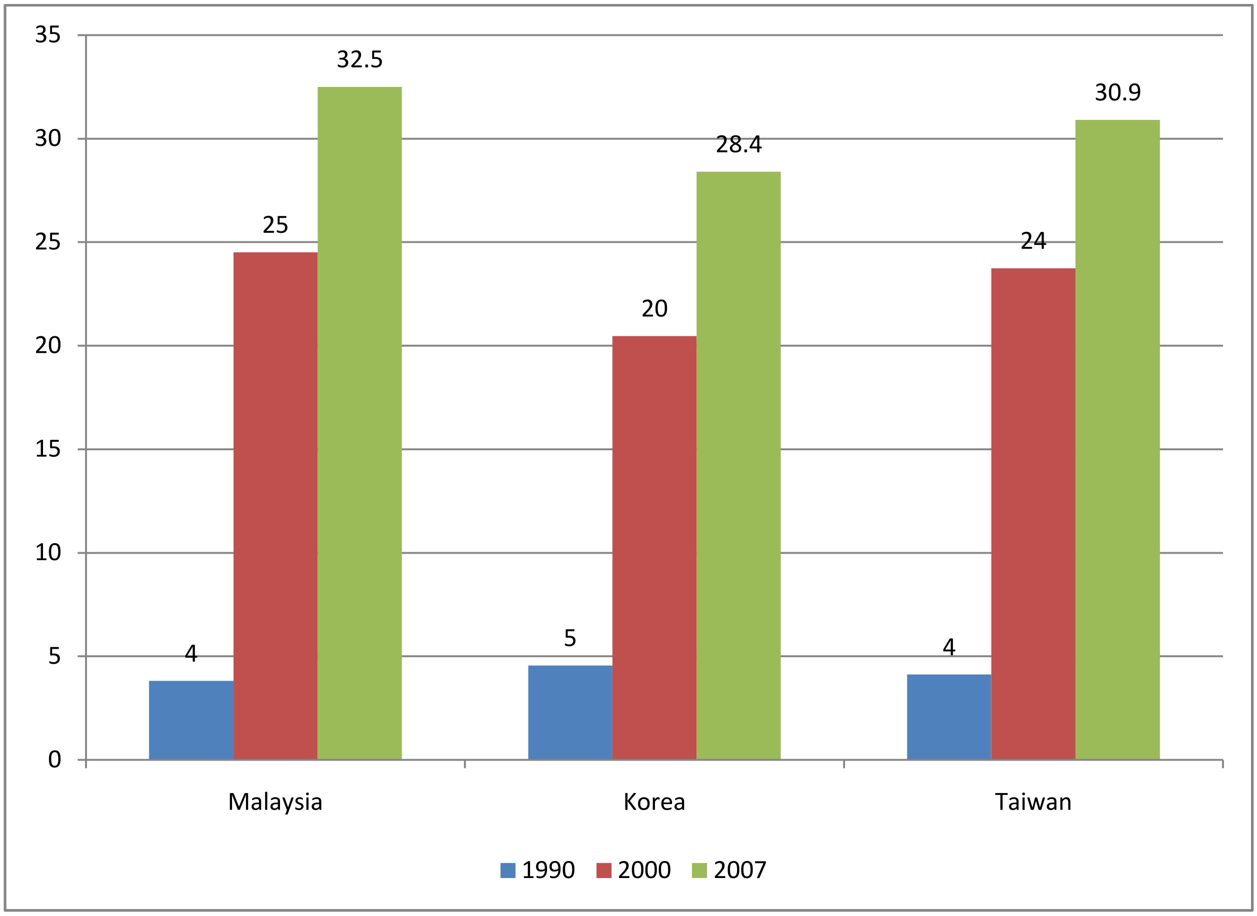
Exports and imports of Malaysia and Korea also showed significant rise. However, IC exports from Taiwan overtook IC exports from Korea in 2008. Nevertheless, the IC trade balance of Taiwan and Korea were positive while that of Malaysia remained negative in 2008.

Figure 2: IC Exports, Malaysia, Korea and Taiwan, 1990-2008 (US$ Billions)



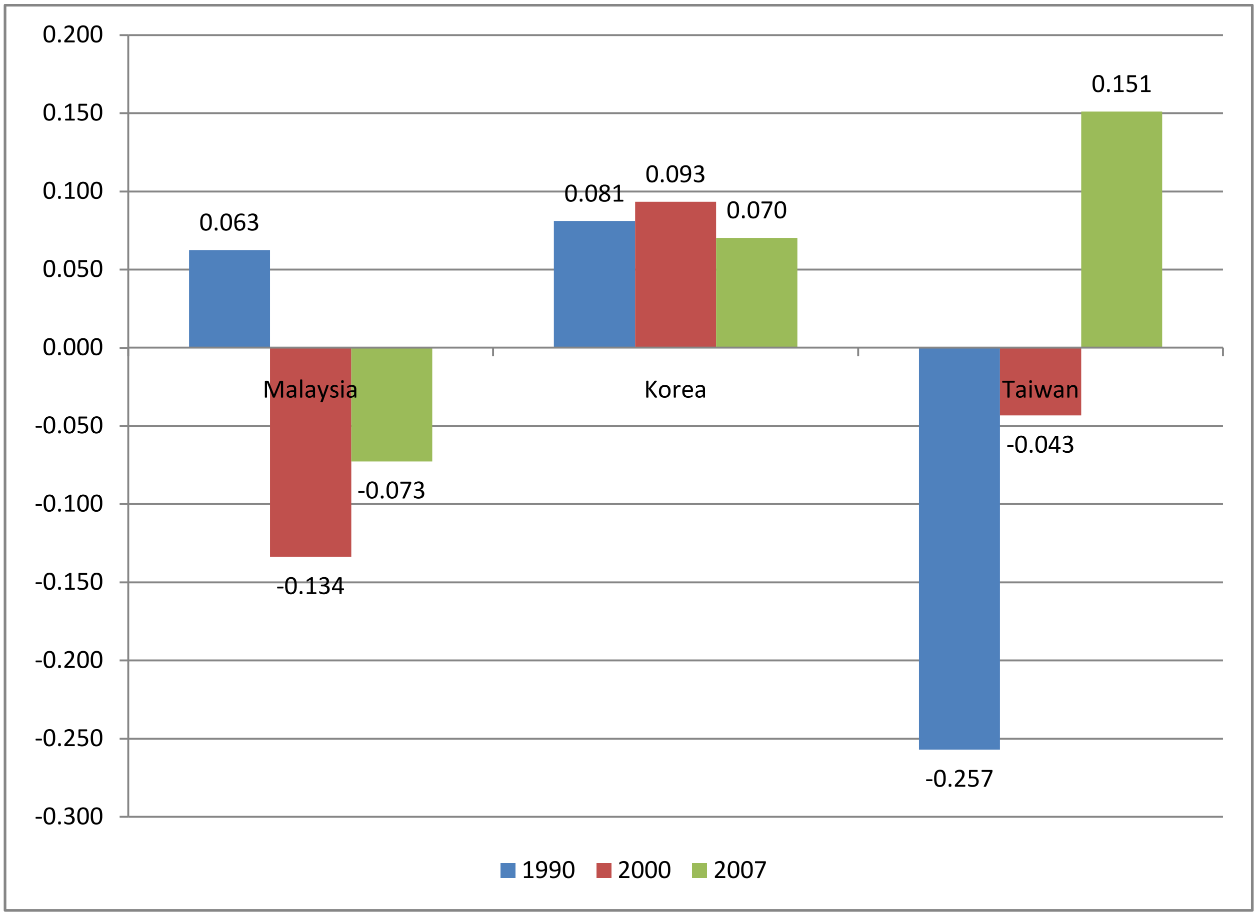
Source: WTO (2010: Appendix Table 11.55)

Figure 3: IC Imports, Malaysia, Korea and Taiwan, 1990-2008 (US$ Billions)



Source: WTO (2010: Appendix Table 11.56)

Figure 4: IC Trade Balance, Malaysia, Korea and Taiwan, 1990-2007



Note: Trade balance was computed using the formula (exports-imports)/(exports + imports).

Source: WTO (2010: Appendix Tables 11.55 and 11.56)

The trade balance implications should also take cognizance of ownership implications as foreign capital accounted for 58 percent of fixed capital of the electronics industry in Malaysia in 2005 (Rasiah, 2010b: 16).[6] Thus, it can be argued that the actual trade benefits enjoyed from the national firms of Korea and Taiwan will be much higher than the multinationals from abroad in Malaysia simply because the latter repatriated profits back after allocating their investment and operating expenditure in the country.

[6] Foreign ownership in the electric-electronics industry rose from 70 percent in 1968 to its maximum share of 91 percent in 1993 before falling to 80 percent in 2001 and subsequently to 58 percent in 2005 (see Rasiah, 2010b: 16).

Stage specialization

In the absence of trade data by stages of value, it is instructive to use a typical IC value chain to discuss specialization by stages of IC firms in Korea, Taiwan and Malaysia (see Figure 5).The IC value chain is ‘u-shaped’ with assembly typically enjoying the lowest and capacity implant development and specifications enjoying the highest value added. This exercise is important to show the sophistication of economic activity associated with IC production in Korea, Taiwan and Malaysia. Trade data tends to mask mastery of value chains thus making it difficult to show whether the value added of IC production in one country is superior to that of another country.

Korean firms are highly centralized and occupy all segments of the IC value chain. Samsung Electronics and Hynix Semiconductors have all the stages with most of the assembly and testing relocated in Southeast Asia and China. Korean firms also have the high end stages of chip implant development and designing in the United States and sales offices in a number of countries. Despite a dispersal of operations across the globe Korean firms have largely internalized their activities so that hierarchical command is a major mode of coordination in their operations. In addition, Korean chaebols are highly centralized as Samsung has its own consumer, telecommunication and industrial electronics firms. Korean firms are at the frontier of DRAMs, SRAM and SDRAM and NAND flash.

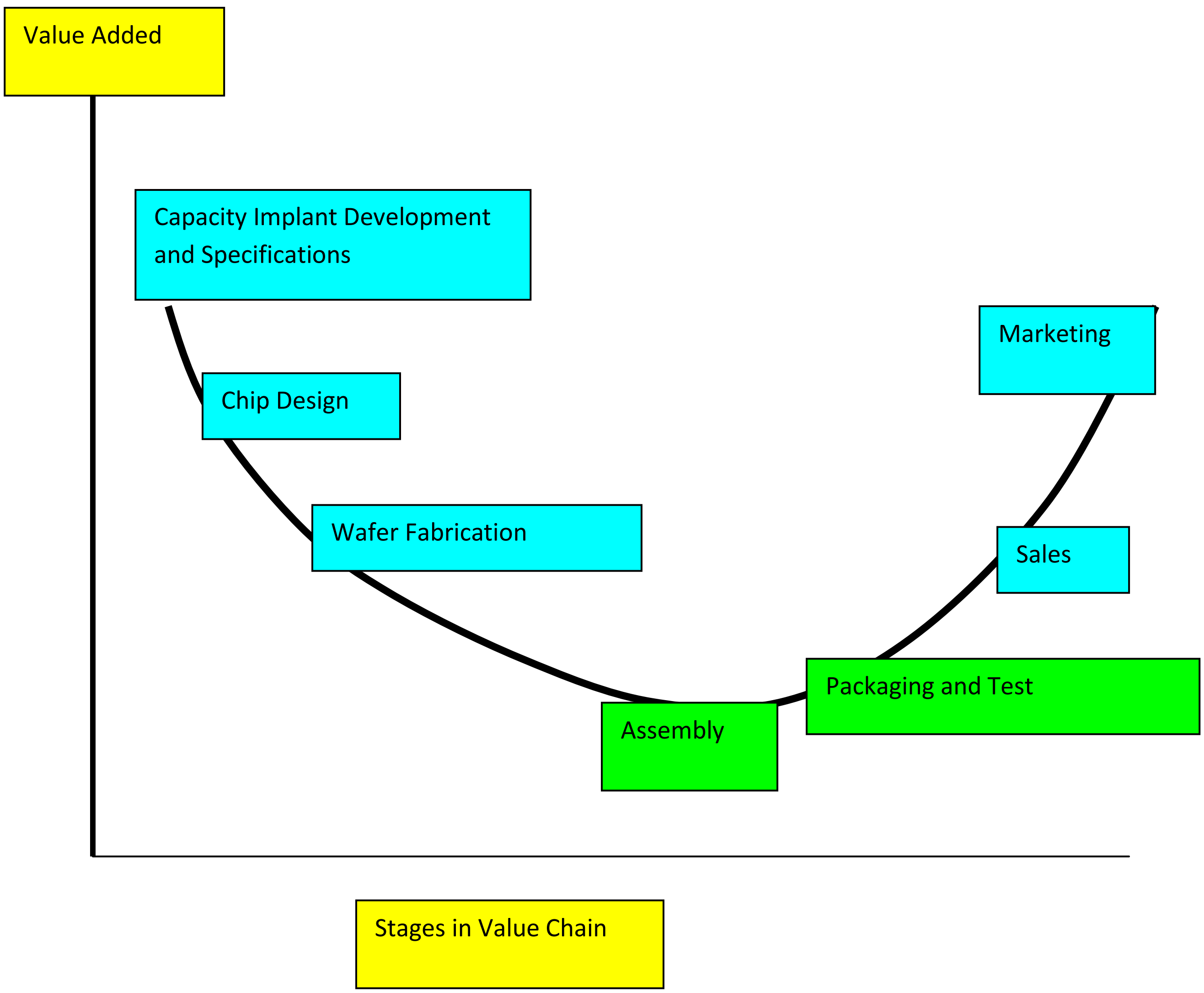
Taiwanese IC firms are highly de-verticallized with contract operations dominating ownership. TSMC, UMC and Vanguard are contract manufacturers. While some designing and R&D on areas such as chip implant is undertaken, these firms specialize mainly on wafer fabrication and designing activities. Because of their dependence on just one segment, these firms are highly networked with buyers and suppliers. The location of these anchor firms has given rise to tremendous demand for the proliferation of designing firms such as Phison around them in Taiwan.[7] Hence, while the division of labour is short in Korean IC firms because of vertical integration, it is high in Taiwan because of de-verticallization. Like Korean firms, Taiwanese firms have also relocated their low end assembly and testing operations in Southeast Asia and China. Taiwanese firms also hold major sales offices in North American and Europe. TSMC undertakes 12” wafer fabrication in both logic and DRAMS, and has started to fabricate microprocessors since 2009.

IC production in Malaysia is dominated by low end assembly and test activities. Because of the lack of upgrading to high value added activities, IC production in Malaysia has come under tremendous pressure from firms in China, Philippines and Vietnam. Also, IC manufacturing in

[7] Phison specializes in flash chips and outsources its designs for fabrication to other firms (Interviews with Phua Kein Seng by the author on 16 November 2008 in Hsinchu City.)

Malaysia is dominated by foreign multinationals with specialization primarily in assembly and test activities. The national firms of Silterra and 1st Silicon, and in addition, the foreign owned Infineon (power chip) and Osram have started wafer fabrication at the turn of the millennium.

Figure 5: Value Chain of ICs, 2010



Product sophistication of lead national firm

The sophistication of product technologies of national firms is one measure of technological capabilities of particular countries. Foreign multinationals in a number of countries undertake the low end aspects of production such as assembling and testing. Even where R&D is off-shored it tends to involve only the peripheral aspects of it (see Amsden, Tschang and Goto, 2001).[8] The lead national IC firms of Korea, Taiwan and Malaysia in 2010 are overwhelmingly Samsung Electronics, TSMC and Silterra, and hence the discussion in this sub-section focuses on them.

Samsung Electronics was founded in 1969 at Suwon as Samsung Electric Industries to manufacture electronic appliances such as TVs, calculators, refrigerators, air conditioners and washers (Samsung_Electronics, October 1, 2010). Samsung Semiconductor and Telecommunications was registered in 1975 (Kim, 1997). Samsung imported semiconductor machinery and equipment, and using the licensing route started producing chips in the 1970s until 1983 when it obtained proprietary technology from Micron of the United States and Sharp of Japan (see Edquist and Jacobssen, 1987). Utilizing its newly acquired knowledge, Samsung became the first Korean manufacturer of low-cost, relatively low-tech, 64-kilobit dynamic random access memory (DRAM) chips. It eventually leapfrogged all other IC firms to propel DRAM technologies. Samsung was using 30nm fabrication process technology to produce its latest chips in 2009, giving the firm a big advantage over its rivals (Nystedt, 2010). In 1984 Samsung fabricated and produced its own 256K DRAM chip and subsequently the 1 megabyte DRAM chip in 1986. It produced its 1M and 2G DRAMs in 1996 and 2009 respectively. Samsung accounted for 40.4 and 34.3 percent of the DRAM and NAND flash market share in the first quarter of 2009 (Samsung Electronics, October 1, 2010). Clearly Samsung is the most sophisticated of the IC firms examined in this lecture having become the world's leader and shaper of DRAM and NAND flash technologies.

TSMC was founded as a joint venture between Taiwan capital and Dutch capital in 1987. Using R&D support from ERSO, the firm ventured into contract fabrication of wafers. From achieving mastery of the fabrication of logic circuit wafers, TSMC gradually entered into SRAM, SDRAM and DRAM chips. Intel outsourced microprocessors for fabrication to TSMC in 2009 (Osborne, March 2, 2010).[9] Being a contract manufacturer using OEM and ODM facilities, TSMC seldom gets to have its products listed for comparisons. The Taiwanese firms of Nanya, Powerchip, ProMos and Winbond were among the top ten producers of DRAMs in the world in 2009.

Malaysia's lead national IC firm, i.e. Silterra was founded in 2001, though, its rooting started when the Malaysian Institute of Microelectronics Systems (MIMOS) acquired VLSI Technologies in 1996. Delayed somewhat by the 1997-98 Asian financial crisis, the firm started operations at Kulim High Tech Park in 2000 using 0.25 micron CMOS technology (see Table 1).

[8] Vernon (1973) had made this observation when arguing that firms prefer to confine their latest technologies to their parent countries because of greater national support.
[9] Intel outsourced its 'Atom" microprocessor fabrication to TSMC in 2009 (Shilov, July 27, 2007; Osborne, March, 2, 2009).

It managed to upgrade its facilities to fabricate 0.13 micron CMOS chips from 2006 using 8" wafers.

Table 1: Technology Trajectory of Lead National Firms

	Korea	Taiwan	Malaysia
	Samsung	TSMC	Silterra
1975	Started		
1976-1982	Acquisitions, Hirings and Licensing		
1983	64K DRAM		
1984	256K DRAM		
1986	1M DRAM, 1M SDRAM		
1987		Incorporated	
1988	4M DRAM	Hiring personnel and contract fabrication	
1990	16M DRAM		
1992	256M DRAM		
1996	1G DRAM		
1997			
1999	256MB NAND		
2000	516MB NAND		Started with 0.25CMOS
2001	1G NAND	Range of DRAMs, SDRAMs and SRAMs	0.22 and 0.18 CMOS
2002	2G NAND		
2003	4G NAND		
2004	8G NAND	12" wafer	
2005	16G NAND	NAND	8MB SRAM
2006	32G NAND		0.13 micron CMOS
2007	64G NAND		
2008			
2009	2 G DRAM	Microprocessors	

Note: Samsung also produces SDRAMs and SRAMs.

Source: Compiled from Kim (1997: 88), Rasiah, Kong, Lin and Song (2009); Authors' interviews (2007)

Patent take up of national firms

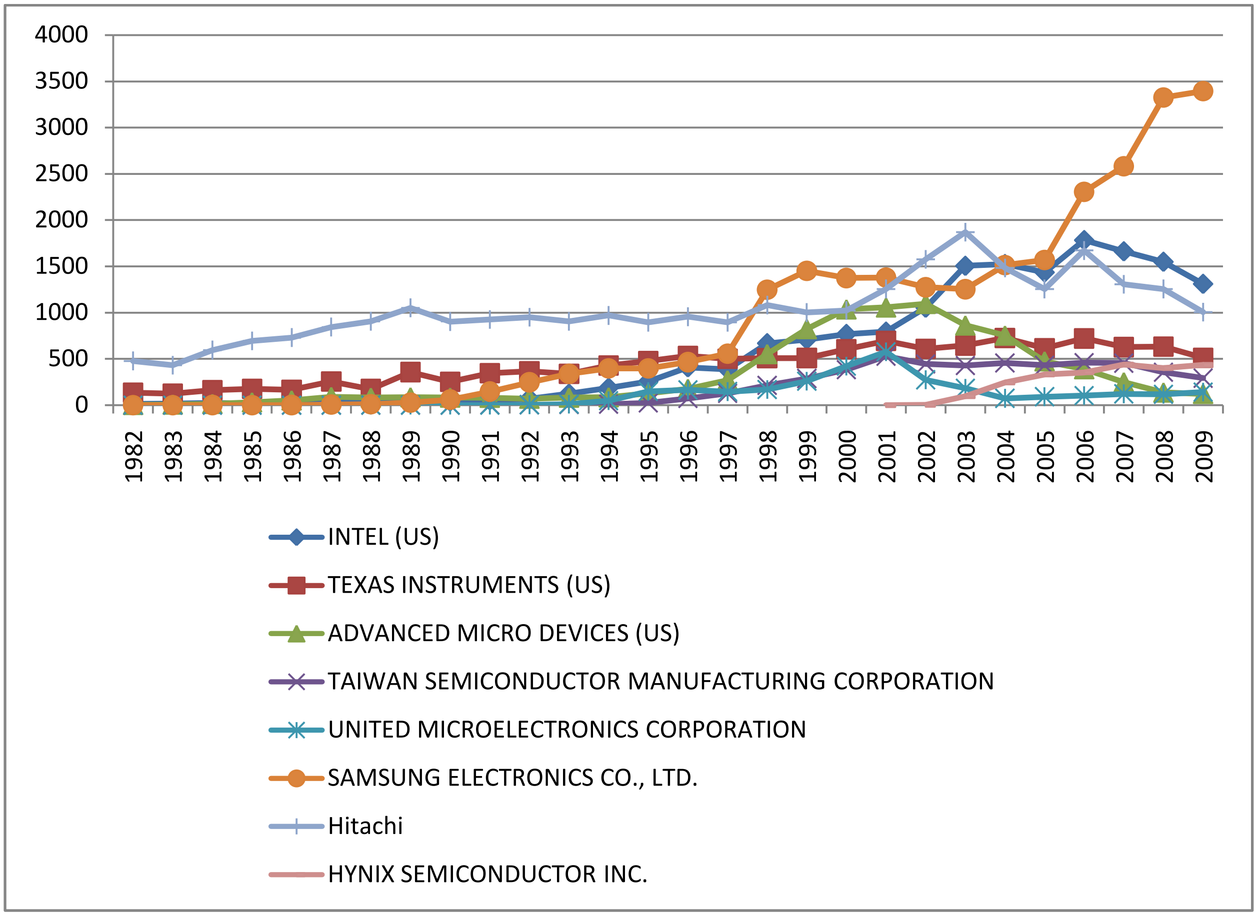
Although not exhaustive, patent take up is one proxy to compare the technological capabilities of IC firms, especially if they are at the technological frontier. A patent take up analysis should be carried out carefully though, as the highly centralized structure of Korean firms would mean that patent filing will be very much internalized and hence, reflected in their higher numbers compared to the highly de-verticallized structure of Taiwanese firms.

As shown in Figure 6, Samsung Electronics caught up with and leapfrogged all its competitors from 1998 to 2002, and since 2005 in patent take up in the United States. Except for the period of 1998-2005 when the Asian financial crisis of 1997-98 destabilized the Korean economy (Chang, 1998), the take up of patents by Samsung Electronics has continued to rise. In fact, Samsung Electronics has enjoyed a sharp expansion in patent take up in the United States in the period of 2006-2008.

Korea's second largest IC firm, Hynix Semiconductor (originally Hyundai Semiconductor) started taking patents in the United States in 2002. Its patent take up rose sharply from 4 in 2003 to 438 in 2007 before fluctuating to 399 in 2008 and 435 in 2009 (see Figure 6). Clearly both Korean firms have taken more patents than any other Asian firm in 2009 with Samsung being first and Hynix Semiconductor being fifth.

For a contract manufacturer, which largely relies on designs of buyer firms, TSMC and UMC have shown remarkable take up of patents in the United States (see Figure 6). Although the number of patents taken have either fallen or stagnated since 2002, TSMC still had more new patents than AMD since 2005. Apart from Samsung Electronics, all other firms have shown a falling trend in patent take up in the United States, which could be a consequence of the global financial crisis that shrunk consumer demand in the major markets.

Figure 6: Patents Granted in the United States, Top IC Firms, 1982-2009 (Numbers)



Source: USPTO (2010)[10]

In contrast, Silterra had only taken 15 patents in the United States over the period of 2001-2006, but have since not managed any in the period of 2007-2009 (see Figure 7). Over the period of its existence from 1985, MIMOS took 5 patents in the United States, and all of it in 2008. The remaining national wafer fabrication firm in Malaysia, i.e. 1st Silicon, has yet to patent in the United States. Foreign multinationals operating in Malaysia – e.g. the subsidiaries of Intel, National Semiconductor, AMD, Freescale Semiconductor, Semiconductor Components, Texas Instruments and Chartered Semiconductor in Malaysia have taken more patents than national IC firms but they are still significantly behind the lead IC firms in Korea and Taiwan. Hence, national firms and organizations in Malaysia have a monumental task to catch up with Samsung Electronics, Hynix Semiconductor, TSMC and UMC.

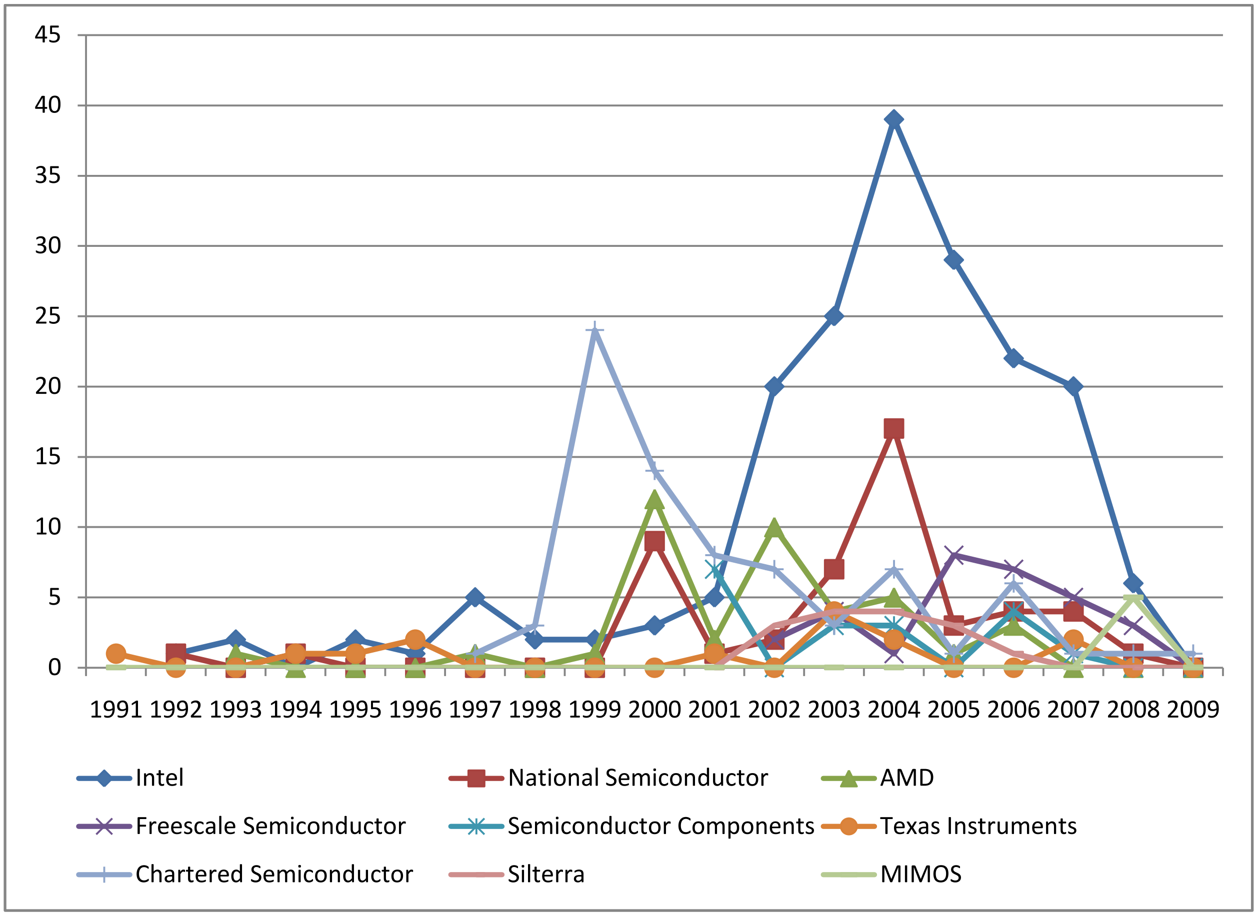
[10] I am grateful to Wong Chan Yuan for compiling the data for me.

Against the background of massive strides taken by the lead national IC firms in Korea and Taiwan, Silterra and 1st Silicon's performances are a pale shadow compared to theirs. Silterra competes in CMOS logic technologies down to 0.13 micron, high-voltage, and mixed-signal radio frequency technologies (Silterra website, 2010). With a capacity to run 40,000 8 in wafers per month, Silterra helps its customers through effective networking with intellectual property providers of design, and easy migration and scalability to smaller geometries technologies.

The chairman of Silterra, Mr Jalaluddin Jarjis, when interviewed showed tremendous knowledge of the steps needed to manage a technological catch up by Silterra.[11] He noted that unless the government can offer a long term commitment with the requisite capitalization and sectoral policies to promote designing, it will not be possible for the firm to follow the path taken by IC firms in Korea and Taiwan. It seems that Silterra has done well to achieve full capacity utilization to break even with operational expenditure. A key official from its holding company who did not want to be named reported that Khazanah Nasional is looking to sell off its stakes in Silterra. Given the yield-driven investment-oriented approach of Khazanah this may be the right strategy for the holding company, but the government should ensure that its new owners take on board the scale and knowledge-based properties of the industry in which the firm operates. Given the argument that ICs have arguably one of the strongest increasing returns properties to act as enablers of other industries (see Rasiah, 2005), the government should examine the experiences of Korea and Taiwan to re-steer national IC firms in Malaysia.

[11] Telephone interview conducted on 17 September 2010 in Kuala Lumpur. I am grateful to Mr Jalaludin Jarjis for his well informed and frank replies to my questions.

Figure 7: Patent Take Up in the United States of IC Firms in Malaysia, 1991-2009



Source: USPTO (2010)

Revenue performance

Whatever the drivers of growth and technological capabilities achieved, in the long run it has to be matched by the revenue performance of firms. We use the proxy of firm-level revenue to compare the performance of the top IC firms in Korea, Taiwan and Malaysia.

Samsung Electronics earned the second highest revenue from ICs in both 2005 and 2008, and its revenue grew in the period when that of the leading revenue earner, i.e. Intel, fell (see Table 2). TSMC's rise is more meteoric when revenues are examined carefully. It rose from the rank of 8th in 2005 to 4th in 2008 with revenue also rising strongly. Hynix Semiconductor maintained its 10th position in 2005 and 2008.

In contrast, Silterra reported having recorded revenues of around US$150 million a year over the period 2008-2009.[12] This amount is miniscule compared to the revenues earned from IC sales by Samsung, TSMC and Hynix. Because of the short experience of Silterra (10 years) compared to Samsung Electronics (35 years) and TSMC (23 years) it may still be useful to support its activities with greater focus on reaching the technology frontier.

Table 2: World's Top Integrated Circuits Firms by Revenue, 2005 and 2008 (US$ Millions)

	Nation	2005		2008	
		Revenue	Rank	Revenue	Rank
Intel	United States	35395	1	34490	1
Samsung Electronics	Korea	17838	2	20272	2
Texas Instruments	United States	11300	3	11618	3
TSMC*	Taiwan	8217	8	10556	4
Toshiba	Japan	9045	4	10422	5
STMicroelectronics	Italy	8870	5	10325	6
Renesas Technology	Japan	8266	7	7017	7
Qualcomm	United States	3457	18	6477	8
Sony	Japan		9	6420	9
Hynix Semiconductor	Korea	5599	10	6182	10
Infineon Technologies	Germany	8297	6	5903	11
AMD	United States	3936	16	5808	12

Note: * Because TSMC is a contract manufacturer it does not produce and sell its own chips.

Source: RMG and Associates (n.d) http://www.maltiel-consulting.com/Semiconductor_Q2_09_growth_maltiel_semiconductor.html, downloaded on October 4, 2010

In DRAMs, the Korean firms of Samsung and Hynix occupy the first and second positions in global market share, accounting for 54.9 percent of world revenue earned in the second half of 2009 (see Table 3). Five Taiwanese firms were in the top ten, accounting for a total market share of 13.7 percent. TSMC is not on the list because it does not use its own brand name. No Malaysian national firm is involved in the production of DRAMs.

[12] Reported in Silterra website.

Table 3: Market Share of World's Top DRAM manufacturers by Revenue, 1st half of 2009

Rank	Company	National Origin	Sales (US$ Millions)	Market share (%)
1	Samsung	Korea	4,924	33.3
2	Hynix	Korea	3,189	21.6
3	Elpida	Japan	2,705	18.3
4	Micron	United States	1,762	11.9
5	Nanya	Taiwan	830	5.6
6	Powerchip	Taiwan	601	4.1
7	Winbond	Taiwan	312	2.1
8	ProMos	Taiwan	153	1.0
9	Etron	Taiwan	136	0.9
	Others		183	1.2

Note: 3rd and 4th quarters added from original source.

Source: DRAMeXchange, Jan. 2010 (reproduced in Shilov, January 29, 2010: 2).

It is obvious that national IC firms from Korea and Taiwan have outperformed national IC firms in Malaysia in all aspects. Samsung is the world's leading firm driving DRAM and NAND flash products. TSMC has continued to be the world's leading contract manufacturer of fabricated wafers having entered microprocessor fabrication in 2009. Although the Malaysian government attempted to support a catch up in the industry, this came much later than in Korea and Taiwan. Its lead national firm of Silterra has stopped upgrading beyond the 0.13 micron CMOS technology using 8" wafers since 2006. In addition, while a critical mass of designing firms have linked up with wafer fabrication plants in Korea and Taiwan, the two national IC fabrication plants in Malaysia are heavily dependent on foreign design firms to sustain operations.

4. Policy Differences

This section attempts to explain why national IC firms have performed far better than those in Malaysia. A number of reasons typically explain why a set of firms have done better than others. While firm-level strategic management is a vital explanatory variable, as evolutionary and heterodox economists have argued, the regulatory framework is critical when driving latecomers in IC production – as it is characterized by lumpy knowledge-intensive investment - from infancy to the technology frontier. Government policy was central in the early expansion of IC production in all three countries, and hence, is the focus of the analysis in this section. It is useful to use the evolutionary framework of mapping the critical elements from national, regional and sectoral innovation systems to explain the differential performance of national IC firms in Korea and Taiwan compared to Malaysia. It has to be noted that the regular occurrence of crisis in the industry – largely driven by intense competition and overproduction – has caused major shakeouts (Rasiah, 1988). The pioneering private IC firm of Fairchild sold its operations to NS because of the crisis. RCA was acquired by UMC, while Japan's Hitachi has contracted in size with its IC name of Renesas. Mathews (2006) has argued that the government of Taiwan deliberately targeted the entry of national IC firms during moments of crisis when the incumbents are weak. Brown and Linden (2009) documented how the crisis has continued to shape the industry. Obviously, the crises that have gripped the industry has opened rather than hindered opportunities for latecomers to emerge and thrive. This section, thus, attempts to explain the role of government policies facing IC production in effecting the institutional change essential for spearheading technological catch up in the three countries.

Assembly by foreign multinationals started off IC production in Korea and Taiwan in the late 1960s, and Malaysia from 1972 following the opening of export processing zones (Muto, 1977; Scibberas, 1977; Lim, 1978; Rasiah, 1988; Kamal, Young and Rasiah, 1988). However, the substantive routes taken to move up the IC value chain in these countries was not through upgrading in these multinationals. National firms became the policy target of the Korean and Taiwan governments for technological catch up. Imports and adaptation of machinery and equipment and the absorption of process technologies, acquisition of ailing foreign firms, and gradually in-house development through the hiring of Korean engineers and scientists carrying tacit and experiential knowledge from foreign firms helped Samsung to reach the technology frontier in DRAM chips in1984 (see Edquist and Jacobssen, 1987; Kim, 1997). Samsung has since been shaping the technology frontier in DRAM and NAND flash chips. Samsung, Hyundai, and LG Electronics back-integrated from consumer and telecommunication products to launch semiconductors (KSIA, 2005). Strong government support but through the central role of ITRI labs using acquired and home grown knowledge were key to technological catch up in Taiwan. Although there were two national fabrication plants and multinationals such as Intel, National Semiconductor and AMD have upgraded into designing activities; IC production in Malaysia is still dominated by low end assembly and test activities (see Rasiah, 2010c).

It is the successful movement upwards of national firms in the IC value chain that became the basis for the selection of Korea and Taiwan as lessons for this lecture.[13] Indeed, Samsung electronics has become the shaper of technology in DRAMs and TSMC has become the most sophisticated and successful foundry-based wafer fabricator. Other national firms in these countries have also made significant progress – e.g. Hynix of South Korea, and UMC, Asus and Vanguard of Taiwan. This section is devoted to discussing the upward movement of the lead IC firm of Korea, i.e. Samsung Electronics, and the lead IC firm of Taiwan, i.e. TSMC in patent take up (a proxy of technological sophistication) and revenue ladders.

Macro-Micro Coordination

Given the lumpy investment required to promote the scale- and knowledge-intensive fabrication of semiconductor wafers, governments' role in supporting Schumpeterian innovation rents, and their paramount role in coordinating and ensuring a stable macroeconomic environment is critical. Macroeconomic considerations played a critical role in the emergence of IC production in Korea and Taiwan as both industry-wide crises, as well as, macroeconomic crises has played a critical role in the evolution of the industry (see Rasiah, 1988; Mathews, 2006; Brown and Linden, 2009). Rapidly shortening product cycles and the miniaturization process in the face of intense competition between rivals have often caused major shakeouts in the industry. Indeed, Moore's law had depicted that the minimum line width of ICs will half with the circuits doubling every 24 months. Although there were concerns that Moore's law in the fabrication of complementary metal oxide semiconductors (CMOS) was reaching its limits because of the materials used (see Brown and Linden, 2009), the dynamic role of Samsung Electronics in the shaping of dynamic random access memories (DRAMs) helped lower the miniaturization process further to 12 months (see Rasiah, Kong, Lin and Song, 2010). Wafer fabrication requires scale and knowledge and acts as an anchor in the IC value chain with high use of knowledge intensities. Its investment is not only lumpy, it faces enormous fluctuations in demand with competition making price movements volatile (Rasiah, 1988: 33). Firms in Taiwan managed to separate fabrication from design thereby reducing the direct need to employ a critical mass of designers and R&D specialists. TSMC became the largest contract manufacturer of fabricated IC wafers but its success requires heavy embedding in a network of designers and buyers (Rasiah and Lin, 2005). It is for these reasons latecomer involvement in wafer fabrication requires careful coordination with the macroeconomic variables such as interest rates and capitalization.

The early export-processing zone type assembly operations that were began in the 1960s was superseded by the opening of the first local semiconductor firm in Korea in 1974. The launching of the Heavy and Chemical Industries (HCI) by the government in 1975 was pivotal in attracting Samsung's entry into semiconductor chip manufacturing, though, the firm was also motivated by

[13] Singapore was not selected because of the lack of both local and foreign firms showing significant movement towards the technology frontier of IC production (see Amsden, Goto and Tschang, 2001).

its own self-expansion plans to supply its consumer electronics subsidiaries (Kim, 1997: 88). Samsung Electronics entered IC production in 1975 at a time when Korea's balance of payments was seriously affected by the first oil crisis that drove oil prices up by 4 times. Instead of floating the won to clear the deficit, the government maintained a stable won-US$ exchange rate so as to prevent a depreciating won from raising import costs for firms that included Samsung Electronics which had to import machinery and equipment as well as pay royalties over the licensing of technologies. The Korean chaebols continued to enjoy subsidized credit but its productive returns were driven by export quotas (performance standards) imposed by the government (Amsden, 1989). The freeing of exchange rates advocated by the Fleming-Mundle model would have cleared the balance of payment problems, thereby raising import prices and lowering export prices. [14] However, that would have also wiped out all the nascent heavy and high tech industries.

Taiwan followed a slightly different path by maintaining macroeconomic stability through avoiding large balance of payments deficits while at the same time supporting R&D through the use of government funds to support the activities of the Industrial Technical Research Institutes (ITRI) that were begun in 1974. Entrepreneurs also faced subsidized credit in Taiwan. The Electronics Research and Service Organization (ERSO) was the body that coordinated R&D on ICs. While government-funded incubators from ERSO led the initial entry into IC fabrication, the government also acquired RCA to the rooting of United Microelectronics Company (UMC) and provided the initial fillip for the joint-venture with Phillips through the founding of the Taiwan Semiconductor Manufacturing Corporation in 1987. Taiwanese firms' participation in R&D and designing only expanded strongly after the government built the high tech infrastructure at Hsinchu Science Industrial Park (HSIP) in 1980, and provided grants for Strategic technical Projects (STPs). The STPs were initiated in 1979 but became successful when free rider problems were eliminated through the creation of matching funds (Rasiah and Lin, 2005). Whereas much of government grants went directly to electronics firms in Korea where firms such as Samsung Electronics and Hynix (formerly Hyundai) Semiconductor internalized their R&D and designing activities, IC firms in Taiwan were generally nurtured in the incubators with much of the R&D confined to ERSO in the formative years. In Korea, IC firms carried out such activities right from the beginning. Nevertheless, the government in both Korea and Taiwan recognized that its direct support was necessary especially in the formative years and ensured that it was retained even during economic blips.

[14] Clearly the McKinnon-Shaw model that claimed that high interest rates attracted savings on the one hand, and filtered investments to capable entrepreneurs on the other hand, did not occur in reality. While the curb market rates were high the rates that faced the cheabols were low (see Chang, 1994).

Strategic Mechanisms

Governments in Korea and Taiwan intervened to promote strategic industries and IC production was one of them. The early formulation of strategic industries in Korea started in 1969 and was launched in 1970. However, government's initiative to promote IC production started in 1975 under the Heavy and Chemical Industry Promotion program. Samsung Electronics took advantage of the generous government incentives and subsidized credit to enter IC production by first acquiring a private firm that was started by a Korean doctoral graduate from Ohio University.[15]

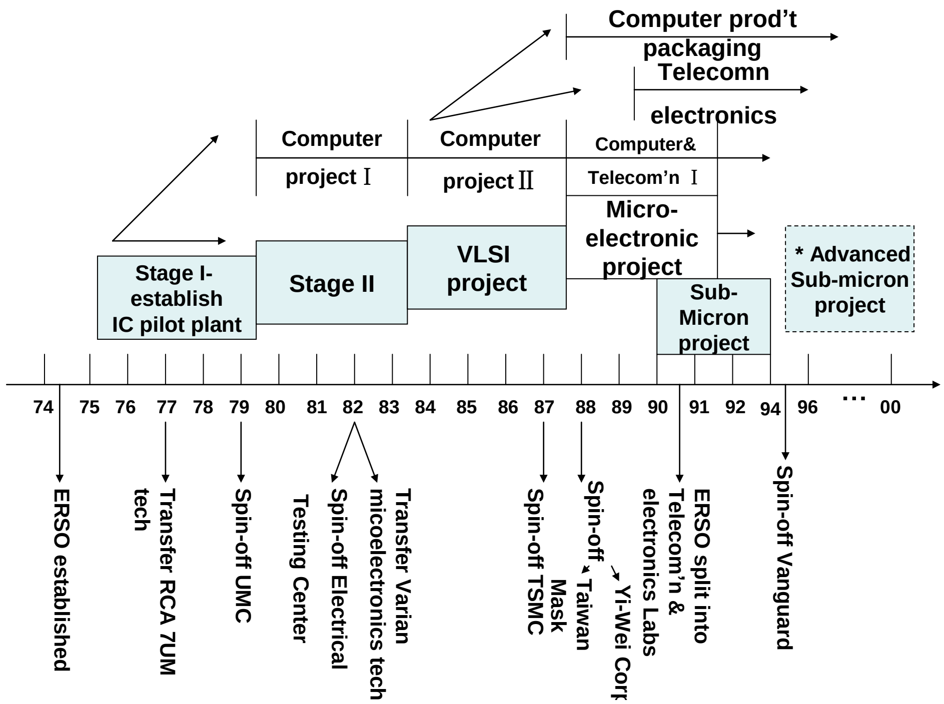
To make up for the lack of technological expertise domestically, the Korean government required foreign telecommunications equipment manufacturers to assist with the operational aspects of advanced semiconductor technology in return for access to the Korean market when Samsung first Semiconductor and Telecommunications first started operations. Samsung benefitted from the subsidized credit and protection in the domestic markets to offset the high royalties it first had to pay for licensing technology from abroad. In addition, the government was also instrumental in monitoring the acquisition of memory technology from Micron Technology, which was successfully rooted in Samsung in 1983. Export quotas were the prime performance standards used by the government to drive competitiveness, including in IC firms in the 1970s. As Samsung became large its in-house command became a major source of coordination to drive catch up. In-house command, then, took over to regulate Samsung's and Hynix performance as efforts were taken to increase patent take up in the United States and to increase revenues. Samsung in addition has a strategic framework to continue to stay ahead in driving the shaping of the DRAM and NAND flash technology frontier.

Foreign IC assembly plants relocated at the Kaohsiung export processing zone in the late 1960s but none were engaged in high value added activities such as designing or wafer fabrication. Through the establishment of the Industrial Technical Research Institutes (ITRI) in 1974 and its specific branch the Electronics Research and Service Organization (ERSO), the Taiwan government began serious initiatives to drive technological catch up in IC manufacturing (see Figure 8). The government undertook the incubation of the key technologies within ERSO and in the case of United Microelectronics Company (UMC), acquired and merged the capacities evolved with that of the American company. ERSO planned the first IC plant over the period of 1975-79. The first step was to install the resources necessary to support R&D in ERSO, which was then followed by the acquisition of the semiconductor division of the Radio Company of America (RCA), a process that was begun in 1977. This development led to the founding of Taiwan's first wafer fabrication firm in 1979, i.e. UMC. The government, then, established an IC testing centre in 1980 followed by electrical and microelectronics firms over the period of 1980-

[15] The firm was started in 1974 but the owner sold it as he could not cope with the inflationary pressures that came with the first oil crisis. Samsung Electronics acquired the firm and appointed the owner initially as its Managing Director (Kim, 1997: p).

83 (see Figure 8). Between 1984 and 1987 the focus shifted to the acquisition of very large scale integration (VLSI). ERSO under the guidance of Morris Chang evolved the technology and subsequently launched a joint-venture with Philips to start the Taiwan Semiconductor Manufacturing Company (TSMC). This project also spun off a number of other microelectronics firms, as well as, its main user, i.e. computers. Taiwan Mask, Yi-Wei Corporation and Vanguard were direct spinoffs of ERSO. In the period of 1996-2000, ERSO concentrated on its final leg to support the development of sub-micron technology. ERSO ended participation in R&D and IC production in 2000 to focus on promotion.

Figure 8: ITRI-based IC projects, Taiwan, 1974-2000



Source: ITRI's annual report, various issues, reproduced in Lin (2009)

Although eclectic in many ways, two broad strategies can be identified in the way IC production was promoted in Malaysia. The first targeted IC multinationals to relocate in Malaysia. From 1972 until 1986, the focus was on employment creation and hence the MNCs confined production to assembly and testing (Rasiah, 1988).[16] From 1986 but especially since 1988 the government used incentives to stimulate foreign MNCs to upgrade. National Semiconductor, the first IC multinational to relocate operations in Malaysia, started assembly activities in Penang in 1972, which was then followed by Hewlett Packard, Motorola, Advance Micro Devices, Texas Instruments, Intel, Mostek, Siemens and Hitachi. ST Microelectronics and International Device

[16] In fact, from 1971 until 1990 government advertisements still used low wage literate girls as a key promotional instrument to attract IC firms to Malaysia (see Rasiah, 1996).

Technology relocated subsequently. The focus expanded from assembly to include testing by the late 1970s.

The first initiative to stimulate upgrading in IC manufacturing started from the second half of the 1980s following the enactment of the Promotion of Investment Act in 1986 arising from the Industrial Master Plan of 1985 (Malaysia, 1986). This initiative came on the back of a UNIDO-led set of recommendations that targeted technological upgrading to higher value added activities that was contained in the Industrial Master Plan of 1986. Incentives became the basis to drive skilling and participation in R&D activities from 1988 when the instruments of the Promotion of Investment Act of 1986 were implemented. Double deduction incentives on approved training and R&D were implemented to stimulate upgrading. However, this instrument did not achieve its desired impact as the latter especially required upfront grants to attract initial participation. Hence, the mature multinationals sought incentives for activities they were already performing (see Rasiah and Osman, 1998; World Bank, 2005).

In the second approach, the government started a microelectronics unit in 1985 within the Prime Minister's department targeted at producing Malaysia's national IC firms. However, the focus on national firms did not materialize in any form until the acquisition of VLSI technologies in 1996. It was targeted at offering the base for rooting through MIMOS the development of national IC fabrication firms in Malaysia. Some elements of the Japanese MITI system of *ikusei* were followed. The fabrication plant was classified as strategic and with that attracted massive investment from the government. A number of the tax breaks, including investment tax credits, capitalization and grants were provided by the government *a la* what was done by the Japanese MITI in the 1950s and 1960s. However, Malaysia's MITI did not form a team to undertake vetting *ex ante*, monitoring and *ex post* appraisal on the licensing, royalty payments, management of MIMOS, monitoring of technological catch up and economic performance. Also, Malaysia's MITI did not create an 'administrative guidance cartel' to regulate competition and coordinate investment among nationals firms in IC production.

In 1990 the government introduced a blueprint to promote high tech industrialization through the Action Plan for Industrial Technology Development (APITD). This was a masterful document that earmarked strategic industries and the linkages to demonstrate how they can spur technological catch up, though; it did not have a roadmap (see Rasiah, 1999). A number of meso-organizations were launched since to spearhead technological upgrading. The Human Resource Development Act of 1992 led to the formation of the Human Resource Development Council, which started collecting the human resource development fund from 1993. Manufacturing firms with employment size exceeding 50 had to contribute 2 percent of their payroll to this fund from which they can then reclaim by showing approved expenditures. MIMOS was corporatized. The Malaysian Technology Development Corporation was founded in 1992 to play the role of venture capitalists. The Malaysia Industry Government High Technology (MIGHT) was formed in 1993 to provide the front for industry, government and university interactions on high technology issues.

There has been some revival since 2009 when the initiatives of the federal government through the consultative body comprising the Northern Corridor Investment Authority (NCIA), the multinationals and state actors managed to attract grants to support a radio frequency integrated design (RFID) centre at the Penang Skills Development Centre (PSDC); with prospects of attracting further support for computer and systems, and flat panel displays. However, the IC industry has essentially stagnated technologically despite substantial participation of multinationals such as Intel's subsidiary in Penang in designing and patent take up in the United States. The New Economic Model (NEM) has embraced the Vision 2020 goals targeted by Tun Dr Mahathir government in 2000 to make Malaysia a developed nation in 2020, but the strategies identified appear both unconventional and unrelated to those used by Korea and Taiwan. Instead of strengthening the regulatory framework by making pre-approval vetting, monitoring and *ex post* appraisal, the NEM has attempted to scale down the regulatory framework.[17]

Knowledge Flows

Given the high knowledge intensity of R&D, wafer fabrication and designing, foreign sectoral sources of knowledge was important as Korean and Taiwanese human capital, endowed with strong tacit and experiential knowledge, were hired by national IC firms. The immigrant community from Europe constituted the human capital that drove R&D in the university and military labs in the United States. This pool was subsequently replenished and expanded with inflows of human capital from the developing world staying back after graduation. National human capital essentially drove technological catch up in IC production in Japan. The quick relocation of knowledge from frontier regions to Korea and Taiwan were critical in quickening the catch process in these countries.

The movement of students from Korea and Taiwan in the 1950s and 1960s to the United States was driven by geo-political reasons as the United States government established strong bilateral ties when it started post-war restructuring in these countries and were supportive of integrating them with their educational systems as they were frontal states facing communist North Korea and China. The high value attached to higher education saw citizens of these countries pursuing their tertiary education there. Many of them sought jobs in the United States when they graduated. Interviews show that the economic base in Korea and Taiwan in the 1960s and 1970s was not particularly ripe to absorb them.[18] As strategic industries were identified and promoted,

[17] The electric and electronics industry is the only manufacturing sub-sector identified for strong support to facilitate economic transformation of the country, but it does not address the fundamental governance issues of nurturing infants to competitors (see Malaysia, 2010: 7).

[18] Interview with the late Linsu Kim in Maastricht on July 21, 2001 on Korea, and Dr Tai-Yuan Wu in Hsinchu City on November 16, 2008.

government in these countries through government-industry consultative councils identified the diasporas as a major source of learning.

Korea and Taiwan benefited from both a relocation, as well as, circulation of knowledge. The significance of tacit and experiential knowledge in driving technological catch up was advanced by Teece (1982), Winter (1987), Mowery, Oxley and Silverman (1996), Cohen and Levinthal (1990) and Song (2002). Using patent take up as the knowledge transfer variable, Song, Almeida and Wu (2003) showed how the hiring of engineers who moved from American to non-American firms assisted the take up of patents in the latter. The relocation brought back directly human capital embodied with tacit and experiential knowledge gained through employment in flagship firms, and university and government research labs in the United States back to Korea and Taiwan. The complete relocation of human capital – developed through first tertiary education and then through employment in high tech firms – provided strategic technical and management expertise, as well as, helped connect Taiwanese firms to the critical networks of knowledge and markets. Morris Chang, Wu Tai-Yuan and David Wang are few of the hundreds of celebrated Taiwanese who returned to run high tech firms in Taiwan.

The second source of knowledge inflow came from brain circulation. Nationals from the countries often flew back to participate in conferences or consultations that benefited national firms domestically, or simply interacted 'virtually' through internet chats to solve a wide range of industrial problems. Such networking – built through a blend of cooperation and markets – have been important in quickening technological catch up in Korea and Taiwan.

While the return of the experienced Koreans and Taiwanese played an important role in raising the human capital for catch up, the government also played important roles to raise the quantity and quality of science and technology education in the countries. Indeed, the focus expanded to masters' and doctoral degrees so that the domestic base expanded for the proliferation of high tech firms such as IC firms. Whereas IC engineers generally joined the large firms in Korea, significant numbers of them used the incubator route to start their own firms. Phison is one of the examples where the chief executive officer and main founder scaled up his masters' thesis findings into producing the early designs for fabricating flash chips.[19] Vogel (1991) and Saxenian (2006) had documented extensively the massive investments the government made to upgrade science and technology-based education in Korea and Taiwan. Hence, the sum of foreign and domestically trained R&D scientists and engineers in the population of these countries rose to exceed 4,000 in 2006 (see Table 4). Similarly, government expenditure through grants dominated R&D expenditure in GDP in these countries in the 1970s and 1980s. By the 1990s, private expenditure R&D had become important. The R&D expenditure share in GDP of Korea and Taiwan recorded 3.2 and 2.6 percent respectively in 2006, which is fairly close to that of Japan (see Table 5). As private R&D expanded the government began reducing its own

[19] The chief executive officer, Phua K.S. is a Malaysian who had originally tried to start his own company in Malaysia.

contribution, and in Taiwan, direct government funding of IC projects ceased in 2000 (Lin, 2009: 23).

Whereas Korea and Taiwan managed to turn brain drain into brain gain by appropriating strong knowledge flows into the development of national IC firms through purposive mechanisms, the brain gain programme of the Malaysian government connected little with the actual evolution of technological capabilities of national IC firms. The original chief executive officers of Silterra and 1st Silicon were foreigners instead of top Malaysians with tacit and experiential knowledge holding high positions in internationally recognized IC firms. For example, Loh Kin Wah, the Chief Executive Officer of Qimonda, which made 3.6 billion Euros with 13,500 employees world-wide is Malaysian (Yoshida, July 7, 2007). Since the tacit and experiential route to catching up with frontier operations has proven to be successful in Korea and Taiwan, the Malaysian government should make attempts to attract them to drive technological catch up in national IC firms.

In addition, despite the massive efforts in the 1990s to expand science and technology education in the country, that included the opening of private universities after the Private Universities Bill was approved in 1995, and growth in the number of public universities to 24 by 2009, the share of R&D scientists and engineers in the population in Malaysia only reached 372 in 2006 (see Table 4). Not only are the numbers small, there are also complaints about their quality. Drawing from a survey of 103 firms, Rasiah (2010b) reported that many IC firms complained about the quality of graduates they were hiring from national universities. To make matters worse, the R&D expenditure as a share of GDP of Malaysia was only 0.64 percent in 2006 (see Table 5).[20]

[20] Interviews with a MOSTI official on August 25, 2010 in Putra Jaya show that this figure had fallen to 0.21 percent in 2008.

Table 4: Researchers in selected Asian countries, 1996–2006 (no. per million persons)

	1996	1998	2000	2002	2004	2006
China	448	390	549	630	710	927
Japan	4,909	5,170	5,111	5,087	5,316	5,568
Korea	2,209	2,023	2,334	3,023	3,298	4,162
Singapore	2,535	2,977	4,139	4,398	5,087	5,736
Taiwan	3,326	3,794	3,922	3,103	3,579	4,159
Malaysia	90	154	276	295	503	372

Source: UNESCO (2010: Table 19).

Table 5: Gross expenditure on R&D as a share of GDP in selected Asian countries, 1996–2006 (%)

	1996	1998	2000	2002	2004	2006
China	0.57	0.65	0.90	1.07	1.23	1.42
Japan	2.80	2.80	2.90	3.17	3.17	3.40
Korea	2.60	2.55	2.69	2.53	2.85	3.23
Singapore	1.45	1.76	1.92	2.16	2.24	2.39
Taiwan	1.88	1.98	1.96	2.2	2.44	2.58
Malaysia	0.22	0.39	0.49	0.69	0.63	0.64

Sources: UNESCO (2010: Table 26).

It is clear that successful technological catch up in technology and scale-intensive industries in latecomers have involved marked learning strategies from technological leaders, with particularly strong opportunities during times of crisis. Kim (1997) lucidly articulated how Korean IC firms moved from creative duplication to innovation to reach the frontier. Malaysia's experience with national IC firms engaged in wafer fabrication is much shorter and their performance results fall far short than that of IC firms in Korea and Taiwan. Arguably the most significant difference between the policies of Korea and Taiwan, and Malaysia on the promotion of IC production is the regulatory framework. Different channels were used to learn and innovate but what led them to become successful experiences is the use of an accountable regulatory mechanism that was characterized by effective vetting, monitoring and *ex post* appraisal of the various strategies, *meso*-organizations and incentives introduced to stimulate catch up in IC production. Through either acquisition or licensing or both strategies, governments have assisted latecomer firms to establish a strong starting foundation, which has then been followed by the development of national capabilities through the implementation of a regulatory framework where *ex ante* vetting is accompanied closely by performance monitoring and *ex post* appraisal. Accountability to ensure performance standards was assured from performance measures – that in IC production included export quotas and patent take up in the United States.

5. Conclusions and Implications

This lecture focused on the framing of the regulatory parameters for driving a catch up in IC production in Malaysia by screening the existing literature and the experiences of national IC firms and the regulatory regimes they faced in Korea and Taiwan. Given the role of path dependency and cumulative accumulation of knowledge, successful latecomers creatively duplicated the incumbents to reach the technology frontier. Such catch ups were targeted by some governments such as Taiwan during moments of industry-wide and global crises when the opportunities during the shakeout appeared better against incumbents. Because the key high value added stages of IC production such as wafer fabrication is highly capital-intensive and in addition, designing is knowledge-intensive, governments have played a pivotal role in the origin and the catch up process (see Amsden, 1989; Amsden and Chu, 2003). However, the experience of the latest Korean and Taiwanese firms arriving at the technology frontier shows that the evolutionary argument that all the bits of the puzzle need to connect and coordinate effectively is critical for interventions to work. The key bits of the catch up puzzle included the relocation of foreign stocks of knowledge through licensing, acquisitions, knowledge diffusion through brain gain and circulation and connectivity to buyer-supplier firms, and macroeconomic coordination to support the risky and uncertain but knowledge-intensive activities of IC wafer fabrication and designing. However, the most critical driver of technological catch up has been the government's role in vetting *ex ante*, monitoring and appraising *ex post* the successful transfer of knowledge and technological catch up.

Although Korea and Taiwan were heavily dependent indirectly on exports, the government offered both protection and subsidies to industries classified as strategic and characterized by high knowledge intensities. Malaysia included IC production in its promotional kit of strategic industries since 1988 for the same reasons (MITI, 1989). Attempts by the Malaysian government to support the emergence and growth of national firms are consistent with the initiatives of Korea and Taiwan from the 1970s. The opening of MIMOS, and strategic classification of IC production, and a wide range of *meso* organizations that were stated in the 1990s are in line with the initiatives undertaken in Korea and Taiwan. The government even acquired a foreign IC firm to root the acquisition and development of national participation in IC production. The lack of a performance-based regulatory framework that vetted *ex ante*, monitored and appraised *ex post*, has restricted the capacity of these initiatives to stimulate technological catch up in national IC firms. Also, the key deficiency facing high tech industries in Malaysia, which is the generation of engineers and scientists domestically and the appropriation of tacit and experiential knowledge from Malaysian talents abroad, has to be resolved for any strategic government efforts to support a catch up for the technology frontier to materialize. However, any effort to withdraw now will be lost opportunity for Malaysia, albeit the circumstances are less favourable now for a catch up in the industry because of the proliferation of wafer fabrication and designing in Korea, Taiwan, China and Singapore. Not only that the industry has had a long history that has generated considerable tacit and experiential knowledge embodied in employees of the IC multinationals in Malaysia, as enablers ICs generate increasing returns by driving its own growth, and that of other industries.

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