Multinational Corporations, Global Production Networks and Technological Upgrading: Evidence from Integrated Circuits Production Firms in Asian Developing Economies

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1. Introduction

The decomposition of production and its dispersal to connect developed sites with less developed sites has been welcome as a boon from where a number of poor countries have enjoyed the opportunity to break in and move up global value chains (Collier, 2006; UNIDO, 2009). The immediate division of labour of such cross-border spread of production has been driven by resource endowments – both natural resources and low wages – along what Froebel, Heinrich and Kreye (1980) had argued to depict the Babbage Principle. Babbage (1835) had conceived the first computer through his efforts to use mathematical, engineering and manufacturing knowledge to design a mechanical structure that could be decomposed by knowledge capabilities. This is different from the view of neoclassical economists as they considered the geographical differentiation of production on the basis of relative prices as a boon that promises to stimulate economic development (Helleiner, 1973). Exponents of the global commodity chains (GVCs) have analysed changes in the drivers of value chains (see Gereffi, 2002; Gereffi, Humphrey and Sturgeon, 2005). This argument was taken up by the exponents of global production networks (GPNs) (Whitley, 1996; Coe, Dicken and Hess, 2008; Quark, 2011) and evolutionary economists (Katz, 2000; Lall, 2001; Rasiah, 2004) have argued that such relocations can only sustain long-run development when the embedding institutions and intermediary organizations are created and strengthened to support technological upgrading.

Using the integrated circuit industry as a case this paper examines the origin and development of the IC industry in East Asia, and observes the evidence to establish the degree of upgrading achieved under different policy regimes pursued by the host-economies. The IC industry is also not only highly knowledge-intensive but it also characterized by frequent crises and miniaturization (see Brown and Linden, 2009). Upgrading is evaluated from movements, if any, in the value chain from lower to higher value added stages of production, and firm-level technological activities. A typology of taxonomies and trajectories is developed for the industry to answer these questions. Firm-level empirical evidence is used to map these developments and drivers. Whereas the bulk of exports of IC exports in Korea and Taiwan were generated by national firms, foreign firms continue dominating IC exports from China, India, Indonesia, Israel, Malaysia, Philippines and Singapore. Yet, national IC firms in Korea and Taiwan benefited considerably from flows of knowledge from multinationals located abroad through licensing, acquisitions, and movement of human capital and flows of knowledge through interactive learning across the globe (see Edquist and Jacobssen, 1987; Cohen and Levinthal, 1990; Mowery, Oxley and Silverman, 1996; Saxenian, 2001; Song, Almedia and Wu, 2003).

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The rest of the paper is organized as follows. Section 2 examines the key theoretical issues addressing economic growth and technological catch up. Section 3 discusses the performance of integrated circuit firms in East Asia. Section 4 focuses on the drivers of technological upgrading. The final section finishes with the conclusions and policy implications.

2. Expansion of IC Component Trade in Developing Asia

The rise in component trade has been documented extensively through the lenses of fragmentation in production (Kimura and Ando, 2003, 2005; Athukorala and Yamashita, 2006). The electronics industry is one of them that have experienced a massive explosion in the decomposition of production with a consequent expansion in component trade. The Asian developing economies became the prime beneficiary of the geographical decentralization in electronics production. The expansion in IC components as a major segment of trade became more marked following the pioneering efforts of Taiwanese firms to specialize in particular segments of production (Kuo, 1983). The volume of IC trade from developing Asia grew rapidly from US$37.1 Billion in 1990 to US$234.2 Billion in 2000 and US$572.6 Billion in 2010 (see Table 1). The most dramatic expansion of IC trade took place in China where IC trade grew from US$0.9 Billion in 1990 to US$26.5 Billion in 2000 and US$243.9 Billion in 2010.

Table 1: Trade in ICs, Asian Economies, 1990-2010 (US$ Billions)

	1990	2000	2010
China	0.9	26.5	243.9
Indonesia	0.2	0.8	3.1
India	0.3	0.6	2.3
Israel	0.3	3.3	3.9
Korea	9.9	45.2	71.9
Malaysia	8.1	43.2	62.3
Philippines	2.1	27.3	29.2
Singapore	6.5	27.0	40.8
Taiwan PC	6.6	45.5	92.4
Thailand	2.2	14.2	21.4
Vietnam	0.0	0.6	1.4
Total	37.1	234.2	572.6

Note: Trade is measured by adding exports and imports.

Source: Calculated from WTO (2011: Appendix Tables 11.55 and 11.56)

Developing East Asia's share in world IC trade rose from 33.4% in 1990 to 37.9% in 2000 and 59.6% in 2010 (see Table 2). China's expansion is the most dramatic as its share rose from 0.8% in 1990 to 4.3% in 2000 and 25.4% in 2010. The share of the traditionally strong exporters and importers of ICs of the small economies of Korea, Malaysia, Singapore and Taiwan either stagnated or fell slightly over the period 1990-2010.

Table 2: Share of World Trade in ICs, Asian Developing Economies, 1990-2010 (%)

	1990	2000	2010
China	0.8	4.3	25.4
Indonesia	0.2	0.1	0.3
India	0.3	0.1	0.2
Israel	0.3	0.5	0.4
Korea	8.9	7.3	7.5
Malaysia	7.3	7.0	6.5
Philippines	1.9	4.4	3.1
Singapore	5.8	4.4	4.3
Taiwan PC	5.9	7.4	9.6
Thailand	2.0	2.3	2.2
Vietnam	0.0	0.1	0.1
Total	33.4	37.9	59.6

Source: Calculated from WTO (2011: Annex Tables 11.55 and 11.56)

While the Asian developing economies have enjoyed strong trade in ICs, the trade balance coefficient of the countries is far from uniform (see Table 3). Among the old bases of IC production experience Korea has recorded rising surpluses from 8.1% in 1990 to 9.3% in 2000 and 20.4% in 2010. Philippines has recorded positive balances over the period 1990-2010, but is widely believed to experience a repatriation abroad of the surpluses as profits by foreign MNCs. Singapore and Taiwan managed to overturn their negative balances in 1990 to positive balances by 2010. In fact, Singapore recorded a massive balance of 70.5% in 2010.

Whereas Malaysia faced a negative trade balance in 2000 and 2010, Thailand recorded negative balances in all the three years. Most IC firms in Malaysia lost their tax holidays by 1995.[2] Incentive structures were instrumental in explaining why Malaysia recorded a positive balance in 1990 as the foreign MNCs enjoying a tax holidays repatriated profits abroad. The same reasons explain the positive balance enjoyed by Indonesia in 2000 when the two foreign MNCs in Batam enjoyed tax holidays.

The largest mover on IC trade, i.e., China has recorded huge deficits over the period 1990-2010. The prime attraction of China for IC firms is the large pool of cheap labor when the firms first

[2] Doraisami and Rasiah (2003) provide evidence of MNCs showing sharply reduced profits or losses in Malaysia upon the expiration of their tax incentives.

began relocating operations from the 1980s. Despite the large pool of IC MNCs producing chips from within, imports still dominate IC trade in China. Industrial and consumer electronics firms in China still rely heavily on imported ICs. Unlike Singapore, Malaysia, Philippines and Thailand, tax breaks were not an important instrument used by China to attract IC MNCs.

Table 3: IC Trade Balance, Asian Developing Economies, 1990-2010 (%)

	1990	2000	2010
China	-70.7	-59.6	-48.4
Indonesia	-79.3	78.9	-40.1
India	-73.1	-75.6	-41.3
Israel	-16.1	8.3	26.2
Korea	8.1	9.3	20.4
Malaysia	6.3	-13.4	-2.2
Philippines	1.5	21.9	13.1
Singapore	-12.5	14.4	70.5
Taiwan PC	-25.7	-4.3	21.2
Thailand	-18.6	-17.5	-12.5
Vietnam	0.0	-70.4	-61.0

Source: Calculated from WTO (2011: Annex Tables 11.55 and 11.56)

The expansion in component trade has indeed offered tremendous opportunities for developing economies to break into the global value chains of cutting edge products such as ICs. However, what is not obvious from the evidence above is whether the relocation of export-oriented production in the developing world has led to technological upgrading that is essential to support sustained improvements in the material conditions of those connecting to global IC value chains. Besides trade balance accounts of particular components do not present a robust picture of the dynamism achieved in each of the sites examined. Whereas in large countries such as China a massive negative trade balance coefficient may not be altogether bad if the imported ICs are assembled into consumer and industrial electronics for export, positive trade balances in countries such as Philippines are often seriously offset by the repatriation of profits by foreign MNCs. Hence, within the limits of data available it is important to investigate in greater detail as to whether the Asian developing economies integrated in IC value chains are actually experiencing are enjoying an upgrading in technology and value added.

3. Theoretical Considerations

There is a wide range of papers that focus on the globalization of production but few actually examine empirically its impact on technological upgrading at the exporting locations. In some cases the decomposition of production is undertaken entirely by multinational corporations so that the microcosm of the firm retains command of the whole value chain. Foreign direct investment is the basis of such a globalized division of labour which spread across borders. In other cases particular stages of production are detached and outsourced to other firms located abroad. Whereas in the first formation multinationals keep control of the value chain through internalized command, control in the second formation is defined by the relative strength of suppliers in value chains though command structures are independent. Technological capabilities of both types of firms at host-sites are often influenced by the presence, level of development and connectivity of host-site institutions and meso organizations. What is important in the context of this paper is to examine what Markusen (1996) referred to lucidly as 'sticky spaces on slippery slopes' when explaining why some locations experience industrial deepening while others remained as moribund sites in the globalization process. More often than not the focus of economic development is on the transformation of physical technologies without much discussion on the important role of macro, meso and micro coordination to ensure that the evolution of firm-level technological capabilities is undertaken without disruptions. Katz (2000, 2001, 2006) and Cimoli and Katz (2003) point out that the lack of committed governments to provide the macro-micro coordinates to insulate firms from structural reforms pressures is a major reason why significant numbers of firms with strong evolving technological capabilities either went down during macroeconomic crises or have been displaced by firms disinterested in pursuing scale- and knowledge-intensive activities in Latin America. Whereas Schumpeter (1934) called for the need to provide productive rents to attract investment into risky and uncertain activities for technological catch up it is also critical that the macro instruments and meso organizations (intermediary organizations targeted at solving collective action problems) are created and connected to firms at the micro level to ensure that the interface between them is smoothly coordinated to stimulate firms movement to the technology frontier. Companies in such activities may crumble rather than compete if exposed early to unbridled currents of competition or especially to sudden external shocks from volatile fluctuations in exchange rates and interest rates. In a knowledge-intensive industry such as semiconductors, three variables are critical in driving technological catch up, i.e. lumpy investments, absorption and eventually production of knowledge embodied in human capital, and large markets to appropriate scale economies (either at the firm level as achieved by Samsung or at the industry level as achieved by firms in Taiwan).

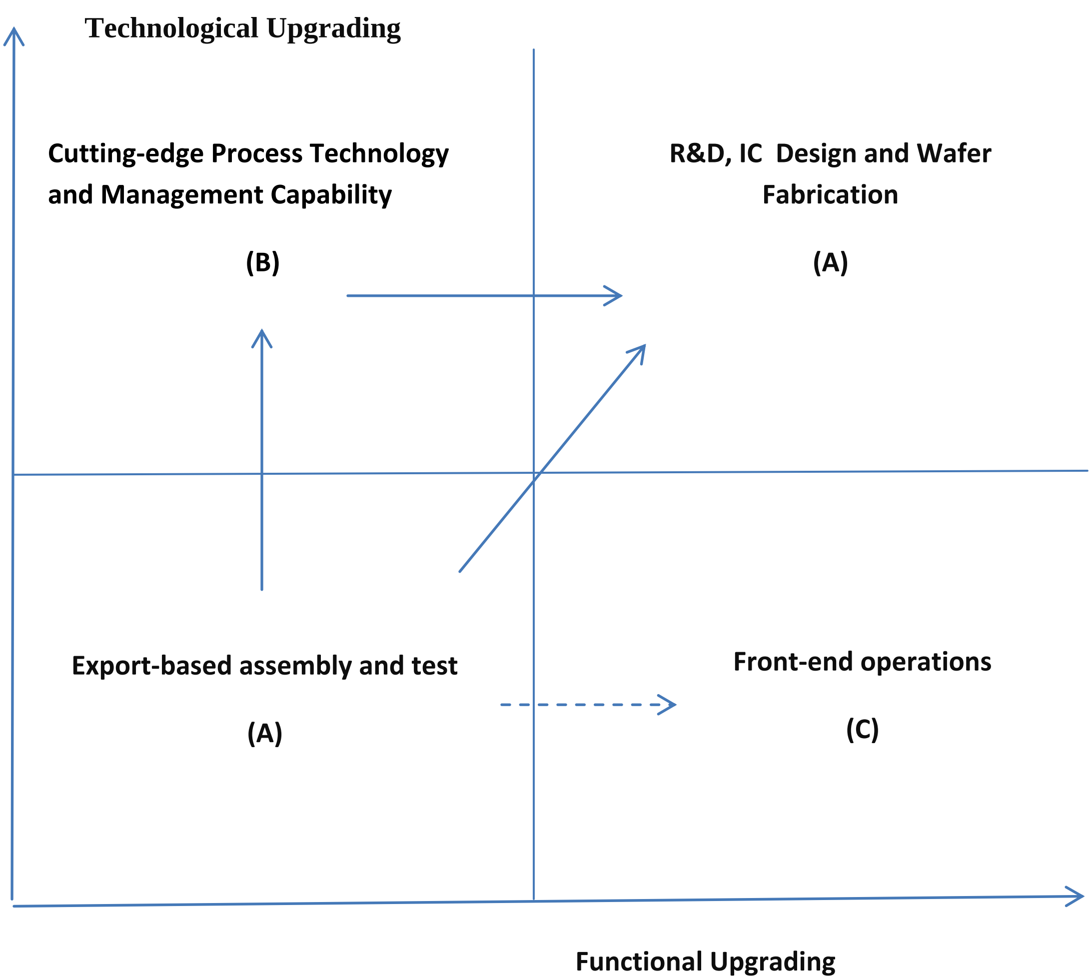
While acknowledging North's (1990, 1994) definition of institutions as the 'rules of the game' and organizations and entrepreneurs as the 'players', Nelson (2008b) argued that a blend of institutions (rather than markets alone taking the lead role) depending on the specificity of industry and timing often shape the conduct of the players. It is Nelson's articulation of institutions and institutional change that fits aptly with Katz (2000, 2001, 2006), Cimoli and Katz (2003) passionate efforts to demonstrate the importance of macro, meso and micro interactions in driving successful catch up. It is important that effective macro, meso and micro coordination takes place to insulate firms' from external shocks as they transform from lower order technological capabilities (e.g. simple activities) to middle order capabilities (e.g., original equipment manufacturing [OEM) with the capacity to generate adaptations to processes and products (incremental engineering) and to higher order capabilities to produce new stocks of knowledge through R&D) (see Rasiah, 1994, 1995). Hence, whereas the market is the superior institution defining the little spaces left behind for other institutions in North (1994), Coase (1937, 1992) and Williamson (1975), the creation and execution of productive rents is important to drive technological catch up in the IC industry.

However, the high incidence of government failures across the world raises the observation that industrial policy is a necessary but not a sufficient condition to drive technological catch up (see Nelson, 2008). 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. Corfo from Chile and Embrear from Brazil made tremendous progress in designing and engineering capabilities, were spawned in government before being passed on to private owners. Fransman (1985) provided evidence of government intervention to promote national firms without having a negative knock on effect on dependent industries. McKendrick, Doner and Haggard (2000) discussed at length the importance of intermediate (meso) organizations in solving collective action problems that arise from critical upgrading activities such as training and R&D. The depth of integration and potential for technological upgrading in particular host-sites in value chains depends very much on the embedding institutions and meso organizations as articulated by the exponents of global production networks (GPN) (see Coe et al, 2004, Coe, Dicken and Hess, 2008).

Arguably the most incisive articulation of the institutional role essential to promote technological catch up comes from Nelson (2008b) who argued for the need to extend the meaning of institutions beyond just the 'rules of the game' as defined by North (1994) to distinguish physical and social technologies. Nelson and Sampat (2001) and Nelson (2008b) suggested that 'institutions' should be used to denote the structures and forces that mold and hold in place prevalent behavioral patterns or social technologies. In doing so Nelson and Sampat (2001) distinguish physical technologies from social technologies by defining the formula (recipe) aspect of the activity as physical technology and the way it is structured, coordinated and delivered as social technology. Technological progress is core to evolutionary economists as it is the propellant of economic progress and structural change (see Nelson, 2008b). Evolutionary economists argue that the influence of any one or set of institutions, or the composition or blend of them within a group in socio-economic action explains how economic transactions and change occur (Nelson and Winter, 1982; Nelson, 2008b). It is in light of this evolutionary explication, that I conceive Katz's (2004) calls for macro-micro coordination as crucial to support technological catch up.

A stylized framework of technological upgrading is depicted in Figure 1. Figure 1 shows capabilities acquired or developed in IC production along two dimensions. In the functional category IC firms first evolve to integrate front-end operations, but relocate or upgrade to participate in R&D, IC design and wafer fabrication. In the second dimension, IC firms absorb best practices, including cutting edge inventory and quality control systems, adaptive engineering and R&D support to upgrade assembly and test activities to raise plant-level productivity.[3] The extent of government support for upgrading to include the integration of R&D, IC design and wafer fabrication will be higher than on simply attracting assembly and test activities.

Figure 1: Technological Upgrading, IC Production, 2012



Source: Authors

[3] We did not include adaptive engineering and incremental innovations (see Rasiah, 1994; Hobday, 1995) as tangibly significant to be categorized as upgrading in this paper. Consistent with the arguments of Amsden, Tschang and Goto (2001) we assume in this paper that supportive R&D is not as knowledge-creating as frontier R&D.

4. Technological Change in IC Production

This section discusses the breaking in and moving up experiences of IC firms in the Asian developing economies. As we have shown in Figure 1, both dimensions of technological upgrading require strong government support because of the publicness of the knowledge processes involved. It is also the basis to distinguish the 'sticky places on the slippery spaces' to use Markusen's (1996) argument. The extent of upgrading technological upgrading through both the dimensions shown in Figure 1, i.e. upward from (A) to (B) as reflected in other R&D activities, and from (A) to (D) has had direct consequences in the take up of IC patents in the United States. It will be shown that the transformation from (A) to (B) and from (A) to (D) were evolved through strong public-private partnerships in Singapore, Israel and Malaysia, while the sheer expansion of national capabilities attracted foreign firms to offshore knowledge-intensive activities. It will also be shown that the technological transformation from especially (A) to (D) and but also from (A) to (B) will be reflected in high patents filed on ICs in the United States.

4.1 Technological Upgrading

Four broad groupings can be discerned from the way IC firms have experienced technological upgrading among the Asian Developing economies. The first group of Korea and Taiwan has already reached the globe's technology frontier through stimulating national IC firms. Despite the contrast in country-size, the second group comprising Israel and India has relied on their human capital endowments to attract category (D) activities as the initial basis of linkage. The third group of Singapore, China, Malaysia and Vietnam has relied on foreign MNCs relocation of assembly and test operations (category A) first followed by incentives to encourage upgrading to category (D) activities. The final group comprising Philippines, Thailand and Indonesia have remained confined to level (A) activities.

Korea and Taiwan

From the evidence shown in Table 4, it is obvious that Korea and Taiwan have the largest number of IC R&D centers among the Asian developing economies integrated in the IC value chain in 2011, and all of them are nationally owned.[4] There is already considerable evidence of extensive government support in the development of technological capabilities through

[4] Because of the wide range of R&D activities carried out by IC firms, we have only included those undertaking exclusively R&D in separate centers as R&D centers. Other firms that undertake R&D to support assembly and test, or engineering or process technology improvements are placed separately as other R&D.

subsidized credit, grants and incentives in the promotion of IC firms from the governments of Korea and Taiwan (see Amsden, 1989; Kim, 1997a, 1997b, 2001; Mathews, 1997; Mathews and Cho, 2000; Amsden and Chu, 2003). While the focus in Korea was on supporting few national firms (Kim, 2003), Taiwan developed the Electronics Research and Services Organization (ERSO) to spin out national firms (Mathews, 1997). National firms grew into vertically integrated firms in Korea but they pioneered specialization by stages in Taiwan.

Foreign sources of knowledge were critical in both experiences as acquisitions, licensing and the hiring of national human capital rooted through American education and working experience in American MNCs played a critical role in the upgrading of national firms to participate in frontier R&D, designing and wafer fabrication activities, which shifted the operations of IC firms from (A) activities to (C) activities (see Vogel, 1991; Saxenian and Hsu, 2001; Saxenian, 2006). The lower value added segment of assembly and test too enjoyed technological upgrading as process and production R&D were introduced by national firms such as ASE. Both countries have retained the promotion of R&D through grants for new firms but stringent performance standards have been used to keep unproductive rents low. The frontier nature of IC operations by national firms in both countries is reflected in the massive take up of IC patents in the United States (see Table 5). In fact, Korean and Taiwanese firms dominated the memory and logic IC technology since the 1990s.

The government also strengthened the intermediary organizations, especially focusing on science and technology education in schools and universities (Vogel, 1991; KSIA, 2005). As the technological capabilities of intermediary organizations grew the large pool of human capital helped attract foreign firms to participate in IC design, and assembly and test activities in Korea and Taiwan with the latter aided by strong process and engineering R&D support.

Israel and India

Israel and India are two IC exporters that are uniquely different from the other Asian developing economies. Endowed with highly qualified technical human capital acquired through both education and employment abroad and in the country, both countries have successfully attracted the knowledge-intensive stages of the IC value chain. Foreign MNCs have relocated sophisticated R&D centers in Israel. The focus of foreign IC MNCs in India is more on IC design, especially in Bangalore. Israel has also benefitted from emigration of engineers from the former Soviet block countries.

By far the most sophisticated foreign operations are found in Israel where there were 1 national and 2 foreign IC R&D centers and 5 foreign chip design centers, 1 foreign firm in other R&D activities, and 2 national and 3 foreign firms undertaking wafer fabrication. Indeed all these activities are knowledge-intensive. India had no IC R&D centers but had 13 IC design centers in 2011. Another 4 foreign firms undertook software programming activities in India. Two national firms carried out assembly and test activities. India enjoyed strong upgrading support in the national firms.

The Science and Technology Ministry of Israel has financed extensively precision control IC design and R&D, a consequence of both the rich pool of highly qualified technical human capital and the pressure it faces to develop high precision intelligence systems and military arsenal to shield itself against difficult neighbors. The development of the Indian Institute Technologies (IITs) produced the technical graduates who became the cornerstone of foreign interest in offshoring IC design and programming activities in India (Ernst, 2006). The build-up of high tech infrastructure in critical cities such as Bangalore and Cyberrabad attracted significant IC related designing activities to India. MNCs such as IBM, Intel, Hewlett Packard and Microsoft have not only started operations in these locations but have also launched endowed chairs to support cutting edge developmental R&D.

Singapore, China, Malaysia and Vietnam

Singapore, China and Malaysia have enjoyed massive IC trade but among the three only Singapore and China 1 national firm each had R&D centers in 2011. Driven by the relocation of assembly and test operations by foreign MNCs since the 1960s, 1970s and 1980s respectively, IC production and export from Singapore, Malaysia and China is still dominated by foreign MNCs. Government provision of investment grants helped attract wafer fabrication by the foreign MNCs since the late 1980s in Singapore and the 1990s in China. The government of Singapore and through the backing of the provincial governments, the government of China[5] also offered R&D grants and laboratories to foreign MNCs to undertake IC design and softer R&D activities related to process engineering and software programming.[6] After much reluctance to include foreign MNCs in the special incentives introduced to stimulate R&D and other high technology activities following the launching of the Promotion of Incentives Act of 1986 (Malaysia, 1988), the Malaysian government approved investment grants to the foreign firms of Infineon and OSRAM to start wafer fabrication at Kulim High Technology Park since 2004 (Rasiah, 2007). R&D grants were also offered to MNCs seeking to undertake supporting R&D and IC design activities (upgrading from (A) to (B) type of activities).

The national R&D center in China also undertook chip design. The one national IC firm in China, Hong Hua also carried out other R&D, wafer fabrication, and assembly and test activities. Among the foreign firms, 11 undertook IC design, 12 R&D to support assembly and test activities. The national firm, Avago, had a R&D center while two other national firms carried out IC design activities in Singapore.

[5] See Rasiah, Kong, Lin and Song (2012).
[6] See Mathews and Cho (2000) on Singapore.

Singapore, China and Malaysia enjoyed operations in both the high value added activities and the low value added activities. National firms in Singapore had 1 R&D center, 3 chip design centers and 3 assembly and test plants. Foreign firms in Singapore had 5 chip design centers, 1 R&D support facility, 7 wafer fabrication plants and 6 assembly and test plants. Foreign MNCs had 3 chip design centers, 1 R&D support facility, 4 wafer fabrication plants and 22 assembly and test plants. National firms had one wafer fabrication plant and 2 assembly and test plants in Malaysia. Vietnam has demonstrated the use of the Singapore strategy of promoting both foreign and national firms as there were 1 each national and foreign IC design centers, 1 other R&D support facility and 2 foreign assembly and test plants in 2011. Vietnamese human capital is being courter *a la* China to return and work at the IC design and R&D support facilities.

Indonesia, Philippines and Thailand

Indonesia, Philippines and Thailand are three locations among the developing Asian economies that only provided security, good basic infrastructure and tariff exemptions on imports to foreign MNCs seeking to relocate assembly and test activities to utilize labor. Foreign IC firms began relocating in Philippines, Thailand and Indonesia in the 1970s, 1980s and 1990s respectively. Whereas Philippines and Thailand had in place prof-foreign investment policies comparable to Malaysia, Indonesia had in place a *pribumi* policy that discouraged American IC firms who preferred owning equity completely. Hence, foreign IC firms only began to relocate in the 1990s when Singapore's Temasik Holdings obtained the lease of Batam Island to manage foreign production operations.[7] All foreign IC firms in these countries were only engaged in low value added assembly and test activities. Given the knowledge-intensive characteristics of the industry, even assembly and test required competitive firms to utilize best practices.

However, although these firms have absorbed best practices in inventory and quality control systems and continuous improvement practices, none had R&D support to back technological upgrading. The Philippines had 15 foreign IC firms in low value added assembly and test activities. Four foreign firms carried out similar activities in Thailand. Three foreign firms were engaged in low value added IC assembly and test activities in Batam, Indonesia. Two foreign firms carried out assembly and test in Vietnam with one of them also undertaking chip design.

Clearly Philippines, Thailand and Indonesia are endowed with massive labor reserves that are significantly larger than Singapore and Malaysia. Yet, foreign MNC operations have remained confined to low value added assembly and test operations without much upgrading to levels (B) and (A). The 1 foreign MNC engaged in chip design was taking advantage of the returning diaspora to support activities of firms located abroad. These countries have not succeeded in stimulating upgrading, and hence, have remained potentially vulnerable to threats of a hollowing out effect in future.

[7] Interview by authors in Singapore on January 12, 2011.

Table 4: Distribution of IC Stages, Asian Developing Economies, 2011

	R&D Center		Chip Design Center		Other R&D		Wafer Fab		Assembly & Test	
	N	F	N	F	N	F	N	F	N	F
China	1	0	0	11	1	12	3	5	1	33
India	0	0	0	13	0	4	0	0	2	0
Indonesia	0	0	0	0	0	0	0	0	0	3
Israel	1	2	0	5	0	1	2	3	0	0
Malaysia	0	0	0	3	0	1	1	4	2	22
Philippines	0	0	0	1	0	0	0	0	1	15
Singapore	1	0	3	5	0	1	0	7	3	6
South Korea	9	0	*	6	0	5	22	1	2	10
Taiwan	7	0	1#	5	0	4	34	5	11	10
Thailand	0	0	0	0	0	0	0	0	4	11
Vietnam	0	0	1	1	1	0	0	0	0	2

Note: N – national; F – foreign; Other R&D refer to R&D associated with supporting process technology, production technology; * - IC design is integrated in R&D centers in Korea; # - Numerous small firms undertake IC design in Taiwan but operate without specific centers.

Source: Official Company Webpages and Annual Reports

4.2 Patent Filing

At the higher levels of the technology ladder, technological change can be measured by patents filed by firms if property rights are important to the industry. Given the massive take up patents by IC firms, this can be a good medium to estimate technological change in the industry among the Asian developing economies.

Korea and Taiwan

Patent filing on ICs in the United States by the Asian developing economies began in 1985 with Israel taking 2 patents (see Table 5). Korea and Taiwan made the move from the late 1980s and 1990s when their take up of patents in the United States rose exponentially through the contribution of national R&D and IC design centers. The massive expansion in the take up of patents by national firms helped attract foreign firms to undertake designing and other R&D

activities in Korea and Taiwan, which is then followed up a rise in the take up of patents by foreign firms from both countries. Clearly, the sheer number of patent take up shows that both Korea and Taiwan are major movers of technology in the IC industry.

Firm-level drive is the prime motivator in the take up patents as IC firms compete to appropriate innovation rents in their scaling activities. In the initial stages Korean and Taiwanese firms aggressively attracted back their national human capital and have connected to interactively circulate knowledge exchange to smoothen patent filing in the United States (see Cohen and Levinthal, 1990; Song, Almeida and Wu, 2003; Saxenian and Hsu, 2001). Also, R&D grant recipients in Korea and Taiwan have to show patents as one of the performance standards when applying for new grants since the 1980s (Lin, 2003). The imposition of such performance standards helped governments of Korea and Taiwan to steer the rents towards productive activities.

Israel and India

The offshoring of high value added IC stages is reflected in the rise of patent take up of foreign firms from Israel and India in the United States. Foreign firms from Israel and India took 257 and 233 patents respectively in the United States in 2010. Whereas no Indian national firms have taken IC patents, Israeli national firms took 11 patents in the United States in 2010.

The take up of patents from Israel and India have risen particularly from the 1990s and 2000 respectively following the return of the diaspora. These developments are primarily coordinated by the firms themselves with the governments of Israel, and the provincial governments of Southern India paying an active role to smoothen the coordination of their activities. In fact, Temasik Holdings of Singapore manages the infrastructure structure and buildings of the IC firms in Cyrabad, India.

Singapore, China, Malaysia and Vietnam

By giving capital grants, Singapore, China and Malaysia managed to stimulate patent take up from the foreign wafer fab and IC design plants, and supportive R&D facilities in 1990, 1995 and 2005 respectively (Rasiah, Kong, Lin and Kong, 2012). National firms in Singapore and China have followed these practices to increase their take up of patents in the United States from the turn of the millennium. National firms take up of patents in Malaysia went from 1 in 2005 to none in 2010 as the government slashed funds for such activities. Vietnam's has enjoyed no patent take up at all but it is too early to judge its experience yet as the first IC firm relocated operations there in 2005.

The timing of expansion of patent take up in Singapore, China and Malaysia is a clear recognition of the importance of grants in funding R&D and designing activities as the numbers only rose following such outlays. However, given the lack of frontier R&D operations by foreign firms, these firms not expected to generate the massive numbers recorded by Korea and Taiwan.

Philippines, Thailand and Indonesia

A couple of foreign MNCs in Thailand took up patents in the United States in 2000-2005 but there were none in 2010 largely because of lack of financial support to stimulate stronger participation in such activities. Foreign firms engaged in assembly and test activities in Philippines took advantage of the human capital to take up 12 and 11 process patents in 2005 and 2010 in the United States. No IC firm in Indonesia has managed to take up any patents in the United States.

Despite the take up of some patents, largely a consequence of long production experience that helped generate problem-solving process engineering adaptations to be patented, all three countries are clearly entrenched at the bottom of the technology ladder among the Asian developing economies connected to IC value chains. In short, these locations are certainly not the ‘sticky places in slippery spaces’ that Markusen (1996) had observed.

Table 5: Patents Filed in the US, IC Firms in Asian Developing Economies, 1985-2010

Year	**1985**		**1990**		**1995**		**2000**		**2005**		**2010**	
Country	**N**	**F**	**N**	**F**	**N**	**F**	**N**	**F**	**N**	**F**	**N**	**F**
China	0	0	0	0	0	3	0	6	9	11	43	95
India	0	0	0	0	0	3	0	8	0	63	0	233
Indonesia	0	0	0	0	0	0	0	0	0	0	0	0
Israel	0	2	0	7	0	25	4	43	6	100	11	257
Malaysia	0	0	0	0	0	0	0	2	1	20	0	55
Philippines	0	0	0	0	0	0	0	1	0	12	0	11
Singapore	0	0	0	1	0	5	0	14	4	58	109	120
South Korea	0	0	60	2	398	0	1374	11	1955	29	5502	110
Taiwan	0	0	1	0	180	3	1082	61	789	0	969	31
Thailand	0	0	0	0	0	0	0	3	0	2	0	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0	0

Note: N – national; F – foreign.

Source: USPTO database.

5. Conclusions

In attempting to answer the question we began with, it is obvious that IC production in Korea and Taiwan has experienced the deepest rooting to show that they will remain sticky for a long time. Israel and India have managed to enter the high value added stages of IC production directly from the start because of the human capital they have developed and have successfully attracted from abroad. IC production have also become sticky in Singapore and China, and to a less extent Malaysia and Vietnam where the provision of grants has attracted participation in level (D) activities of wafer fabrication, IC design and supportive R&D activities. IC production is not sticky in the countries of Philippines, Thailand and Indonesia because of the prime focus of policy to just provide basic infrastructure, security and tariff-free operations to the firms.

The evidence offers implications for the theories we considered at the outset. The GVC approach offered a useful way to explain the spread of the IC value chain globally, but does not explain how and why the drivers of the chains can be shifted from its original cores. Consistent with the exponents of GPN, IC production is most sticky, and indeed, highly rooted in Korea and Taiwan, both of which have evolved the institutions and meso organizations to drive firm-level upgrading to the globe's technology frontier. Consistent with evolutionary arguments, the specificity of timing, structural characteristics of the embedding environment and possibilities offered by the industry have produced uniquely different consequences of technological upgrading among the Asian developing economies connected to global IC value chains. Taking account of its peculiar small base, Singapore has done really well to stimulate upgrading through foreign MNCs as the main drivers. China, Malaysia and Vietnam have the endowments to stimulate the creation of a broad based industry with more national firms, and hence can progress much further with more proactive strengthening of institutions and meso organizations to quicken technological upgrading. IC operations in Philippines, Thailand and Indonesia are not sticky at all because of a lack of emphasis on institutions and meso organizations beyond simply providing the basic infrastructure, security and tariff free operations at export processing zones.

Clearly then governments have the opportunity to attract IC production through either inviting foreign MNCs or support the launching national firms by raising the quality of infrastructure and administering tariff-free operations in particular locations where trainable labor can been pooled. It is obviously easier to pursue the MNC invitation for the poor economies as it is extremely expensive to promote national firms in such knowledge-intensive fields. However, this is only the easier first step in the development of the industry. The more difficult step is to create the conditions for technological upgrading so that the transformation of their operations to higher value added activities to quicken economic development. The successful experience examined in this paper shows that the development of institutions and intermediary organizations through effective coordination between governments and markets is critical to stimulate both technological and functional upgrading in the IC industry.

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