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Economics Series

No. 62, November 2003

Pathways to Innovation in Asia's Leading Electronics Exporting Countries: Drivers and Policy Implications

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Dr. Ernst was invited to prepare this paper for the Democratic Pacific Assembly 2003 Conference, "Common Future of the 21st Century Pacific," on September 18-21, 2003, in Taipei, Taiwan.

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Introduction

Innovation is widely acknowledged to be a major source of economic growth (Pavitt, 1999). In advanced nations, both governments and companies look at innovation as a *strategic weapon* to benefit from globalization, and to survive its competitive pressures. However, in Asia (outside of Japan), *imitation* rather than *innovation* used to be the main focus of development strategies (Kim, 1997). Catching-up with manufacturing capabilities of advanced nations and out-foxing them by becoming faster and lower-cost followers have been the dominant objectives (Ernst and O'Connor, 1992; Hobday, 1995; Lall, 2000; Ernst, Gantiatsos, Mytelka, 1998; Mathews and Cho, 2000; Ernst, 2000).

These strategies have produced impressive results. The emergence of East Asia as a global export manufacturing base during the last decades of the late 20th century is one of the few success stories of Third World industrialization. In IT hardware manufacturing for instance, five Asian countries (China, Korea, Taiwan, Singapore and Malaysia) account for over one quarter of world production. Furthermore, while India has failed to excel as a global manufacturing exporter, the country has firmly established itself as a global export production base for software and information services.

Over the last few years, something new seems to have happened (Ernst, 2003 c). In the midst of a global downturn in the IT industries, Asia's leading IT exporting countries are all attempting to move beyond imitation. They appear to have seized upon new opportunities to create commercially successful innovations in the production of hardware, software, and services. These attempts to enter the global "innovation arms race" (Baumol, 2002) may well have significant implications for the region's position in the global economy as well as for the possibilities and limitations of its development strategies. These developments are poorly understood and under-researched. We thus need to take stock of what is really happening. This paper briefly reviews what is new about emerging pathways to innovation in Asian electronics industries. I demonstrate that the role of Asia's leading players in the electronics industry is changing - from global export production bases for hardware and software, a transition is under way to the creation of commercially viable innovations and standards. I argue that transformations in global markets, production and innovation systems are providing new opportunities for Asian firms that seek to improve their innovative capabilities. To use this potential, however, important changes are required in Asia's innovation strategies, policies and management approaches.

1. Pathways to Innovation

Three important new developments characterize the emerging pathways to innovation in Asian IT industries (**figure 1**[1]): i) global firms are expanding and upgrading their R&D centers in Asia; ii) leading Asian firms are emerging as new sources of innovation and global standards; and iii) this may create new opportunities for smaller Asian firms (the "new technology-based firms" or NTBFs) to enter diverse innovation networks as specialized suppliers.

Most of the literature on R&D internationalization has focused on the relocation of R&D among industrialized countries (e.g., Granstrand, Hakanson and Sjoelander, 1993; Patel and Pavitt, 1998). However, global corporations have substantially increased their R&D in emerging economies, primarily in the above leading Asian electronics exporting

[1] All figures and tables are in the appendix

countries (Reddy, 2000; Liu and Chen, 2003; Ernst, 2003b). This is especially the case in the electronics industry, due to its heavy exposure to three characteristics of the "global networks economy" that I will describe in part 2 of this paper: vertical specialization, global network integration, and the use of IT-based information management. Global corporations in the electronics industry (the "network flagships") increasingly rely on international knowledge sourcing to manage their geographically dispersed global production, distribution and innovation networks (Ernst, 2003a). The network flagships relocate R&D to locations with lower cost of knowledge workers. Equally important is proximity to higher-end specialized network suppliers of components, manufacturing services and knowledge-intensive business services, especially design and engineering support services.

The main carriers of relocating R&D to lower-cost locations in Asia are global brand leaders (e.g. Intel), as well as global higher-tier suppliers, such as manufacturing and design service providers like Flextronics or HonHai or specialized global suppliers of "silicon intellectual property" (SIP), like ARM. All of these firms are currently expanding and upgrading their R&D centers in Asia. They are also outsourcing R&D activities (mostly "blue-collar" design and engineering implementation) to specialized Asian R&D suppliers. Primary locations for such R&D centers and for the outsourcing of R&D are China, India, Taiwan, Korea and Singapore. But the redeployment of R&D centers by global corporations now also covers specialized clusters in lower-tier countries like Malaysia, Thailand, Philippines, Indonesia, and Vietnam.

A second important new development is that leading firms from China, India, Korea, Taiwan and Singapore are emerging as potential new sources of innovation and global standards in sectors like electronic components (especially semiconductors and chip design), digital consumer devices, wireless telecommunication systems, and business process software. Again, a few illustrative examples should highlight the potentially far-reaching implications.

Chip design, a process that creates the greatest value in the electronics industry, has recently experienced a massive geographic dispersion to East Asia (**figure 2**). Excluding Japan, the region's share in the global production of chip designs is projected to grow from around 30% in 2002 to more than 50% in 2008 (iSuppli, 2003). Taiwan has emerged as a primary new location for chip design: five of the top 20 world market leaders are from Taiwan. Korea is following closely behind, with the chip design departments of Samsung, SK Telecom, KT, LG Telecom as the main drivers. The creation of commercial chip designs is also rapidly growing in China and Singapore.

Patents, a widely used proxy for innovative capabilities, also indicate substantial progress. Among patents granted in the U.S., Taiwan did not show up in 1990 among the 10 top countries. Ten years later, in 2000, Taiwan was ranked fourth (with 4,667 patents granted by the US Patent and Trademark Office), ahead of France and the UK, and Korea was # 8, ahead of Italy, Sweden and Switzerland (**figure 3)**.

In digital consumer devices and mobile communications systems, serious efforts have been made to upgrade **system development** and **standard-setting capabilities**, especially in "Greater China" (including Taiwan and Hong Kong) and in Korea. For instance, in **consumer electronics**, there are joint efforts by China and Taiwan to develop a new video-disk technology format, called EVD (enhanced versatile disk) that would allow resolution five times higher than the current de facto industry standard

DVD, while helping China's consumer electronics industry to escape full royalty payments to the dominant DVD licensing groups. Beijing E-World Technology, a consortium of 10 Chinese DVD manufacturers, is conducting government-sponsored research, in collaboration with Taiwan's Industrial Technology Research Institute (ITRI), and Taiwanese disk makers and chip design houses.

In **telecommunications**, Korea's afore-mentioned four leading players are all engaged in serious efforts to become major platform and contents developers for complex technology systems, especially in mobile communications. These efforts can build on considerable capabilities, accumulated in public research labs (like ETRI, the Electronics and Telecommunications Research Institute), as well as in R&D labs of the chaebol, to develop complex technology systems like TDX (a switching system) and communication systems that are based on the CDMA (= code-division multiple access) standard.

Another important example is China's attempt to develop an alternative third generation (3G) digital wireless standard, called TD-SCDMA (time-division synchronous code-division multiple access), for which it received approval by the International Telecommunications Union (ITU) in August 2000. The two dominant competing global 3G standards are W-CDMA (compatible with existing GSM operations, and supported by European firms), and CDMA 2000 (compatible with existing CDMA operations, and supported by US firms). The TD-SCDMA standard was developed by Datang Telecom, a Chinese state-owned enterprise, and the Research Institute of the Ministry of Information Industry, with technical assistance from Siemens. To accelerate the implementation of this strategy, Datang has formed a series of collaborative agreements: a joint venture with Nokia, Texas Instruments, the Korean LG group, and Taiwanese ODM (= original design manufacturing) suppliers, a joint venture with Philips and Samsung, and a licensing agreement with STMicroelectronics that will provide the Chinese company with access to critical design building blocks. Such linkages illustrate how integration into global production networks may facilitate Asian attempts to create commercially successful innovations (see part 2).

Of course no serious observer would claim that China, Korea, Taiwan, and Singapore will soon overtake the US, as well as Europe and Japan, as the global leading centers of innovation. Indeed, there is ample evidence that the sources of innovation remain highly concentrated. Of global R&D, 86% takes place in industrialized countries, with the U.S. occupying the leading position with 37% (Dahlman and Aubert, 2001,p.34). For instance, the R&D budget of a U.S. industry leader, Microsoft, at around $ 6.2 billion (for 2003), exceeds China's total R&D budget. The U.S. has raced ahead in the most prized areas of technological innovation, as far as these can be measured by patent statistics. The US "innovation score" measures the number of patents granted by the US Patent Office, multiplied by an index that indicates the value of these patents[2]. Since 1985, the US "innovation score" has more than doubled, a rate far better than any other country (CHI Research, 2003). In 2002, all 15 leading companies with the best record on patent citations were based in the US, with nine of them in the IT sector (CHI/MIT 2003).

However, while the capability to produce innovations remains highly unequally distributed, there are clear signs that Asia's leading electronics exporting countries are

[2] The citation index measures the frequency of citation of a particular patent. When the US Patent Office publishes patents, each one includes a list of other patents from which it is derived. The more often a patent is cited, the more likely it is a pioneering patent, connected with important inventions and discoveries. An index of more than 1 indicates that patents are cited more often than would be expected for a specific group of technologies, while less than 1 indicates they are cited less often than expected (Narin, 2000)

gradually strengthening their position in the international division of knowledge creation. In a handful of emerging centers of excellence in Asia, sophisticated innovation and research capabilities appear to have followed the earlier development of electronics manufacturing capabilities.

2. Global Transformations and the Mobility of Knowledge

The new push into cutting-edge research and innovation in our sample countries may actually be less surprising than it may look at first sight. It reflects the new mobility of knowledge through vertical specialization into global production and innovation networks, which in turn may provide new opportunities for "late innovation" strategies. Late innovators have easier access to international knowledge sources, due to four recent transformations in the global innovation system that encompass the "global network economy" (Ernst, 2003d): (1) global flagship networks integrate geographically dispersed production, distribution and innovation bases; (2) global firms outsource R&D to locations with lower costs of knowledge workers; (3) brain drain has produced transnational knowledge communities that can act as highly effective carriers of tacit knowledge; and (4) ICT-enhanced information management can improve the coordination of these diverse networks.

Figure 4 provides a stylized model of how *vertical specialization* (i.e. the dis-integration of firm organization and the geographic dispersion across national boundaries) and *re-integration* of dispersed production, distribution and innovation bases into hierarchical *global flagship networks* facilitate *knowledge diffusion*. **Figure 4** also demonstrates the role played by two complementary enabling forces in enhancing both codified and tacit knowledge exchange: *ICT-enhanced information management* and *transnational knowledge communities*.

Let us first look at the latter two enabling factors. In all Asian countries, but especially in China, earlier "brain drain" has produced overseas communities of engineers, scholars, and managers who are familiar with cutting-edge technology and best-practice management approaches and who understand the dynamics of international product and financial markets. These transnational knowledge communities can play an important catalytic role in the development of domestic innovative capabilities (Saxenian, 2002).

The use of ICT as a management tool can enhance the scope for knowledge sharing among multiple network participants at distant locations (Ernst, 2003a). But these changes will occur only gradually, as a long-term, iterative learning process, based on search and experimentation. The digitization of knowledge implies that it can be delivered as a service and built around open standards. This has fostered the specialization of knowledge creation, giving rise to a process of modularization, very much like earlier modularization processes in hardware manufacturing. As a result, one of the most important recent developments that affect international knowledge diffusion is the rapidly growing trade in intellectual property rights (IPR).

Under the heading of "e-business", a new generation of networking software provides a greater variety of tools for representing knowledge, including low-cost audio-visual representations (Foray and Steinmueller, 2001). Those programs also provide flexible information systems that support not only information exchange among dispersed network nodes, but also the sharing, utilization, and creation of knowledge among multiple network participants at remote locations (Jørgensen and Kogstie, 2000).

New forms of remote control are emerging for manufacturing processes, quality, supply chains, and customer relations. Equally important are new opportunities for the joint production across distant locations of knowledge support services (e.g., software engineering and development, business process outsourcing, maintenance and support of information systems, as well as skill transfer and training). While much of this is still at an early stage of "trial-and-error", global network flagships in the electronics industry now face a huge potential for extending knowledge exchange across organizational and national boundaries. However, the uncertainties and complexities of operating in global markets means that there are agglomeration economies to be derived from dense spatial concentrations of specialized network suppliers. Hence, new opportunities emerge for pathways to innovation in Asian electronics industries.

"Vertical specialization" (or "outsourcing" in common parlance) is no longer restricted to the production of goods and services but now extends to all stages of the value chain, including research and new product development. This may facilitate the implementation of "late innovation" strategies in leading Asian electronics exporting countries. Take chip design (Ernst, 2003b). Until the mid-1980s, captive semiconductor producers (like IBM) and merchant firms (like Intel) did almost all their chip design in-house. The first step of vertical specialization was the separation of fabrication and design. The emergence of independent providers of pure-play "silicon foundry" services gave rise to a proliferation of "fabless" design houses (like Altera) that focused on specific niche markets for integrated circuits.

Over time, a second stage of vertical specialization has occurred *within* the process of chip design itself. A primary driver has been a widening productivity gap between design and fabrication. While the productivity of semiconductor fabrication over the last twenty years has seen a 58% compounded annual growth, the productivity of chip design has lagged behind, with only a 21% compounded annual rate (**Figure 5**). Given this design productivity gap, differences in the cost of employing a chip design engineer have become an important determinant for decisions on where to locate chip design. In light of the fact that the annual cost of employing a chip design engineer in East Asia is between 10 and 20% of the cost in Silicon Valley (**Figure 6)**, it is hardly surprising to find that chip design is being relocated to leading electronics clusters in East Asia that provide a skilled and re-trainable workforce as well as easy access to foundry, assembly and testing services. In addition, radical changes in the methodology of chip design through the so-called system-on-chip (SOC) design have arguably further enhanced the scope of vertical specialization within the process of design. Due to the growing complexity of the design process, a single company is no longer exclusively handling the design for a specific chip. Instead, many companies are contributing, based upon their specific areas of expertise. This leads to the development of "global electronic design networks" that link together design houses, the licensors of specific design building blocks, design service providers, foundries, design tool vendors, design departments of large electronics systems, and brand name companies that are all contributing to the complete chip design solution.

But vertical specialization does not imply that the "Visible Hand" of large manufacturing firms will become invisible (as argued, for instance, in Langlois, 2001), giving rise to a resurgence of market forces. "Integration" is the necessary complement to vertical specialization, and the resultant geographic dispersion: large global corporations (the network flagships) can act as system integrators for the diverse, multi-layered production and innovation networks that have evolved as a result of vertical specialization (Borrus, Ernst, Haggard, 2000; Ernst, 2002b; Pavitt, 2003). Trade economists have recently discovered the importance of changes in the organization of international production as a determinant of trade patterns (for example, Feenstra, 1998; Jones and Kierzskowski, 2000; Cheng and Kierzkowski, 2001). Their work demonstrates that (i) production is increasingly 'fragmented', with parts of the production process being scattered across a number of countries, hence increasing the share of trade in parts and components; (ii) that there is reintegration through global production networks; and (iii) that countries and regions which have been able to become a part of these network are the ones which have industrialized the fastest.

Our model of GFNs builds on this work, but uses a broader concept that emphasizes three essential characteristics (Ernst, 2002a and b): i) *scope*: GFNs encompass all stages of the value chain, not just production; ii) *asymmetry*: flagships dominate control over network resources and decision-making; and iii) *knowledge diffusion*: global corporations (the "network flagships") construct these networks to gain quick access to skills and capabilities at lower-cost overseas locations that complement their core competencies. Knowledge-sharing is the glue that keeps these networks growing. Flagships need to transfer technical and managerial knowledge to local suppliers to ensure that they meet the technical specifications mandated by the flagships. Originally this involved primarily operational skills and routine procedures required for sales and distribution, manufacturing and logistics. Over time, knowledge sharing also incorporates higher-level, mostly tacit forms of "organizational knowledge" required for control, coordination, planning and decision-making, as well as for learning and innovation (Ernst and Kim, 2002).

In short, the reintegration of geographically dispersed specialized production and innovation sites into multi-layered GFNs and the increasing use of IT-based information systems to manage these networks are *gradually* reducing constraints to international knowledge diffusion. GFNs expand inter-firm linkages across national boundaries, increasing the need for knowledge diffusion, while information systems enhance not only information exchange, but also the sharing and joint creation of knowledge. This new mobility of knowledge provides new opportunities for pathways to innovation in leading Asian electronics exporting countries.

3. Policy Implications

To reap these opportunities, considerable changes are required in Asia's innovation strategies, policies and management approaches. Research on Asian innovation systems (e.g., Kim Linsu, 1993 and 1997; Lall, 2000; Hobday, 1995; Ernst, Mytelka and Ganiatsos, 1998; Mathews and Cho, 2000; Naughton and Segal, 2001; Liu and White, 2001; Yusuf, 2003; Amsden and Chu, 2003; Segal, 2003) has emphasized that peculiar features of economic structures and institutions offer quite distinct possibilities for learning and innovation, and hence should be reflected in the design of innovation strategies. Asia's electronics exporting countries thus have to develop their own idiosyncratic approaches to innovation strategies, policies and innovation management. As latecomers to innovation, they are confronted with substantial barriers. At the same time, being a latecomer also conveys important advantages, as it is possible to learn from the mistakes of earlier latecomers to innovation.

But what precisely are the over-riding objectives of "late innovation" strategies? To find out, we use a simple taxonomy of Asian innovation strategies (**Figure 7**). Much of the debate has focused on the transition from "catching-up" to "fast-follower strategies" (e.g., Mathews and Cho, 2000; Chang and Tsai, 2002). "Catching-up" requires the mastery of capabilities that are necessary to implement, assimilate and improve foreign technologies (Kim, 1980). This set of primarily operational capabilities makes it possible to enter a product market after growth has peaked, and to do so as a low-cost producer. "Fast-follower strategies" on the other hand aim at entering a product market right at the beginning of its high growth stage. This requires a broader set of capabilities that now also includes certain aspects of innovation. However, the primary focus of innovation in "fast-follower strategies" is on organizational arrangements that make it possible to combine quick market response ("time compression"), flexible production and systemic cost control across all stages of the value chain through supply chain and customer relations management.

Asia's leading electronics exporting countries have all successfully made that transition, either for hardware or for software production. This raises the question where to move to from "fast-follower" strategies. Research on innovation strategies in industrialized countries (e.g., OECD, 2000) points to "technology leader" strategies. Here the objective is to become a prime mover of knowledge creation, and to set global standards during product introduction. The ultimate objective is to create new "intellectual property rights", especially a broad portfolio of frequently cited "pioneer" patents connected with important inventions and discoveries. However, jumping right into "technology leader" strategies to compete head-on with global technology leaders is an unlikely candidate for late innovation strategies. Very deep pockets are required to finance a massive increase of R&D/sales ratios. This in turn necessitates high margins based on premium pricing during product introduction.

Most importantly, "technology leader" strategies require a massive upgrading of innovative capabilities. As with all changes involving complex technological knowledge, this will be a "difficult, painful and uncertain" (Pavitt, 1999:p.XI) process. To illustrate this, I use a classification of technological complexity of different categories of R&D, developed in Amsden and Tschang (2003). "Fast follower" strategies demanded capabilities in both "process development" (to reduce costs, uncertainties and time-to-market of manufacturing, and to improve flexibility) and "prototype development" (to implement a product or system design as an engineered system through detailed product design and engineering samples). "Technology leader" strategies however require a broad set of capabilities in "applied research" (to transform, modify and recombine known technologies so that they fit new applications), "basic research" (to apply new knowledge for radically new marketable products), as well as in "pure science" (to uncover new scientific principles). To develop such a portfolio of demanding capabilities needs time.

Industrial latecomers may however have an intermediate option: "technology diversification". Defined as "the expansion of a company´s or a product´s technology base into a broader range of technology areas" (Granstrand, 1998:472), such strategies are an attempt to reap technology-related economies of scope. Technology diversification focuses on products that draw "… on several... crucial technologies which do not have to be new to the world or difficult to acquire" (Granstrand and Sjoelander, 1990: p.37). In terms of the above taxonomy of research capabilities, technology diversification focuses on “applied research”. Technology diversification also implies that a company increases its reliance on outside sources of complementary technologies, including foreign ones. Empirical research on Japanese, U.S. and Swedish companies has demonstrated that technology diversification plays a more important role than technology substitution, as seen from the larger number of old technologies in a current product generation, compared to the number of obsolete technologies (Granstrand, Patel and Pavitt, 1997)

Conclusions

To conclude, the four global transformations discussed above have created opportunities for late innovators to engage in technology diversification that did not exist before. Asia’s leading electronics exporting countries may also have important latecomer advantages. They can learn from the earlier experience of Japanese firms that have played a pioneering role in the development of technology diversification strategies (Kodama, 1986; Odagiri and Goto, 1992). Japanese firms pursued this strategy for three reasons: to compensate for the decreasing returns of their existing manufacturing exports; to develop generic technologies that could form the base for penetrating future growth markets; and to avoid the high cost and uncertainty of “technology leader” strategies. Second, technology diversification can also build on existing strengths of Asia’s leading electronics exporting countries in both “process development” and “prototype development”, especially imitation and adaptive engineering, as well as detailed design. And third, Asian firms in the above countries can build on their accumulated capabilities to implement, assimilate and improve foreign technologies, as technology diversification often involves the exchange of knowledge with foreign parties.

Appendix (figures)

Figure 1.

What is new?

1. **<u>Global firms are expanding & upgrading their R&D centers in Asia</u>**
   - global flagships (Intel) ↔ global suppliers (ARM)
   - China, India, Korea, Taiwan, Singapore ↔ Malaysia, Thailand, Philippines, Vietnam
   - product customization & process adjustment → chip & system design

2. **<u>Asian firms emerging as new sources of innovation and global standards</u>**
   - chip fabrication & design
   - patents
   - digital consumer devices
   - wireless telecommunication systems
   - business process software

3. **<u>New opportunities for local NTBFs to enter diverse innovation networks</u>**
   as specialized suppliers of
   - knowledge-intensive support services
   - hardware and "virtual" components

Figure 2.

Chip design moves to Asia*

	2002	2008
Asia's share in global production of chip designs (%)	30	>50

*Asia = Taiwan, South Korea, India, China, Singapore, Malaysia

Source: iSuppli report on IC design, March 2003

Figure 3.

Country Ranking of Patents Granted in the U.S., 1990 to 2000

Rank/year	1990	1995	2000
1.	US (47,390)	US (55,739)	US (85,072)
2.	Japan (19,525)	Japan (21,764)	Japan (31,296)
3.	Germany (7,614)	Germany (6,600)	Germany (10,234)
4.	France (2,866)	France (2,821)	**Taiwan (4,667)**
5.	U.K. (2,789)	U.K. (2,478)	France (3,819)
6.	Canada (1,859)	Canada (2,104)	U.K. (3,667)
7.	Switzerland (1,284)	**Taiwan (1,620)**	Canada (3,419)
8.	Italy (1,259)	**South Korea (1,161)**	**South Korea (3,314)**
9.	Netherlands (960)	Italy (1,078)	Italy (1,714)
10.	Sweden (768)	Switzerland (1,056)	Sweden (1,577)
11.	**Taiwan (732)**	Sweden (806)	Switzerland (1,322)

Source: U.S. Patent and Trademark Office, January 2002

Figure 4. Vertical Specialization, GFNs and Knowledge Diffusion

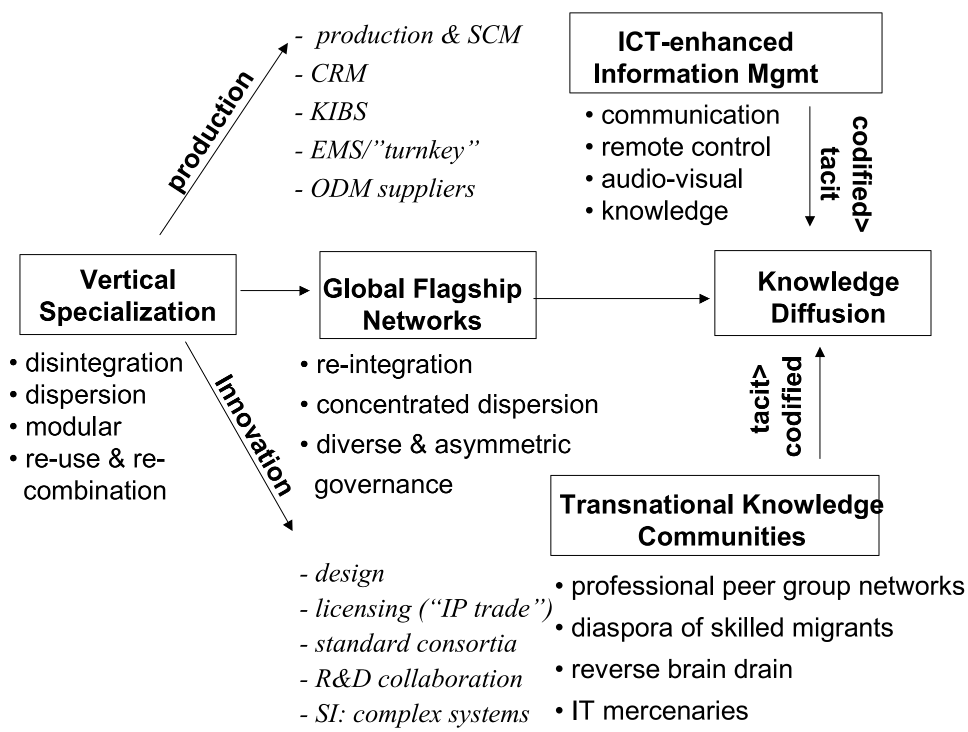

Figure 5.

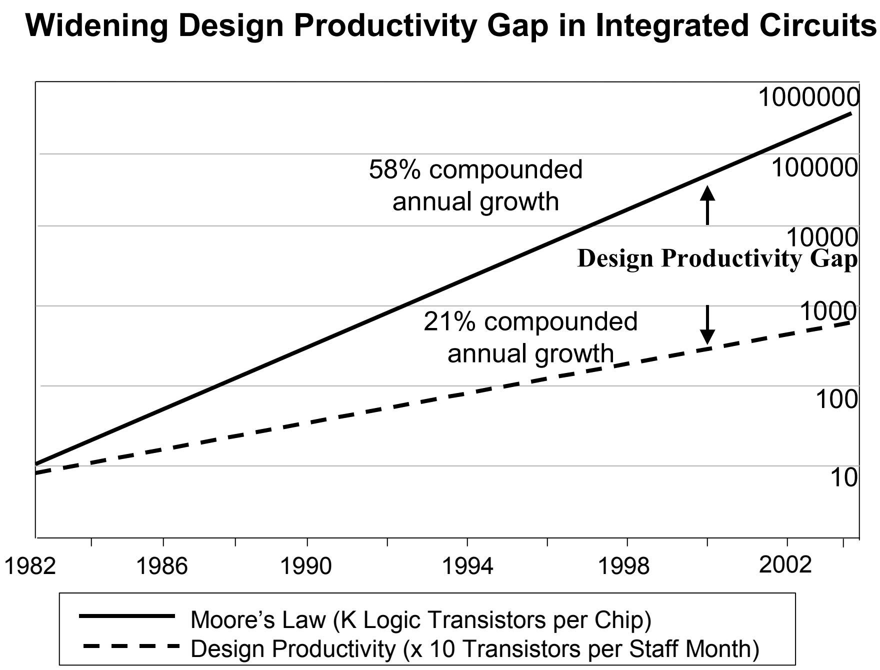

Figure 6.

Annual Cost of Employing a Chip Design Engineer* (US-$), 2002

Location	Annual Cost
Silicon Valley	300,000
Canada	150,000
Ireland	75,000
Taiwan	<60,000
South Korea	<65,000
China	28,000 (Shanghai) 24,000 (Suzhou)
India	30,000

*= including salary, benefits, equipment, office space and other infrastructure.
Sources: PMC-Sierra Inc, Burnaby, Canada (for Silicon Valley, Canada, Ireland, India); plus interviews (Taiwan, South Korea, China)

Figure 7. Strategies and Capabilities – A Taxonomy

Strategies	Definition	Capabilities	Comments
Catching-Up	• enter after growth stage • lowest-cost producer	• operational • implement, assimilate & improve foreign technologies	• decreasing returns (employment; $; TFP) ▪ razor-thin margins↓↓R&D ▪ footloose investment
Fast-Follower	• enter early during growth stage • quick market response • flexible production system • systemic cost control	• process development • prototype development	• profit squeeze↓ R&D • weak marketing skills • where to move to? (paradigm shift)
Technology Diversification	• Recombine (mostly known) technologies to create new products& services • economies of scope (technology)	• applied research •external & international knowledge sourcing • broad IP portfolio	• higher margins & limited uncertainty • new opportunities (vertical specialization, GFNs) • latecomer advantages • build on proven capabilities
Technology Leader	• sets standard during introduction of new product/service	• basic research • pure science • defining standards • superior portfolio of IPs	• high margins (premium pricing) • strong entry deterrents • high R&D cost & risks • cost of adjusting to regulations • lower-cost imitators • “disruptive technologies”

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