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Pathways to Innovation in the Global Network Economy: Asian Upgrading Strategies in the Electronics Industry

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Introduction

The emergence of Asia as a global electronics manufacturing base is one of the few success stories of Third World industrialization. Within a relatively short period, basically the last three decades of the late 20th century, a progressive integration into global production networks, dominated by global corporations (the "network flagships"), has produced a rapid expansion of Asia's production capacity and exports for mass-produced commodity-type electronics products (Ernst, 1997; Ernst and Guerrieri, 1998). By creating jobs and foreign currency, this strategy has provided *"pathways from the periphery"*(Haggard, 1990).

These achievements are now history. They are impressive, but no longer sufficient to generate sustained economic growth. Today, Asia's leading electronics exporting countries are all attempting to move beyond export-led industrialization. By upgrading to higher value-added and knowledge-intensive products, services and processes, they are aggressively exploring diverse *pathways to innovation*. What explains this shift in strategy? How serious are these upgrading efforts? Are these just words, like a few times before during earlier periodic downturns? Or are things different this time? Will R&D and other knowledge-intensive services follow the earlier migration of manufacturing to Asia?

There is little research available that could provide guidance to attempts to answer this question. The study of research policies and innovation systems explores how specific policies and institutional arrangements influence the decisions of firms to develop, commercialize, or adopt new technologies (Mowery, 1994; Freeman and Soete, 1997) and to develop innovative capabilities required to implement these decisions (Pavitt, 1999). However, both theoretical and empirical work is focused overwhelmingly on the leading industrialized economies and their most dynamic innovation clusters. Very few studies address these issues for Asian countries. In addition, empirical research on innovation in Asian countries tends to look back, fighting the old battles about whether markets, governments or foreign investment are the main causes of earlier successes[1].

This paper looks ahead. It argues that Asian pathways to innovation are shaped by the tension between three conflicting determinants. First, a consensus is emerging that there is no alternative to innovation, as traditional export-led industrialization strategies are insufficient to cope with new challenges. Second, there is a widespread fear that a US-centric concentration of economic power and of the sources of innovation may constrain, if not foreclose Asia's attempts to move from upgrading its manufacturing capabilities to upgrading its innovative capabilities. And third, and somewhat paradoxically, there are signs that constraints to the exchange of knowledge are gradually declining in the "global network economy", broadening the sources of knowledge that Asian economies can access and exploit to foster their innovation strategies.

[1] Paraphrasing the late Keith Pavitt (1999), this reflects a bias in academic research: it is a professionally safe option to test established theories.

This argument will be developed as follows. Part one presents data for Asia's five leading electronics exporting countries (China, Korea, Taiwan, Singapore, Malaysia) that highlight their evolving integration in the global electronics industry's production, markets and exports. Part two explores new challenges that have induced these countries to explore pathways to innovation. Improved innovative capabilities are widely seen to be required to cope with decreasing returns of export-led industrialization, and to cope with the impact of external shocks that appear to gain in frequency and destructive power. Innovation is also considered to be essential to cope with two important changes in Asia's economic power structure: Japan's declining role as a regional economic hegemon, and China's new role as a major market and manufacturing base for increasingly sophisticated industrial products, and as a priority investment target for global industry leaders.

Part three examines opportunities for Asian innovation strategies that may result from the new mobility of knowledge in the emerging global network economy. I explore how the traditional boundaries between manufacturing and innovation are blurred by a combination of three inter-related transformations that encompass the emerging "global network economy"(Ernst, 2003, Christensen book):

- vertical specialization ("outsourcing" in industry parlance) no longer is restricted to production (of goods and services), but covers all stages of the value chain, including R&D and new product development;
- the reintegration of geographically dispersed specialized supply bases into multi-layered "global networks of networks" that encompass production, supply chain management as well as product development and design;
- and the increasing use of digital information systems (DIS) to manage these diverse networks to enhance not only information exchange, but also the sharing and joint creation of knowledge.

Part four finally examines diverse upgrading strategies, developed in Asia's five leading electronics exporting countries in response to the above challenges and opportunities. The paper concludes with generic policy suggestions.

1. Asia's Global Network Integration
(incomplete, to be revised)

A progressive integration of Asiars electronics industries into global production networks (GPNs) provides a fascinating example of the benefits that Asian firms can reap from linkages with foreign firms (e.g., Borrus, Ernst, Haggard, 2000; Ernst, 2000, Asia Pacific Journal of Management). Network participation has provided Asian producers with access to the industry's main growth markets, helping to compensate for the initially small size of their domestic markets. It also provided new employment opportunities, and induced Asian network suppliers to develop primarily operational technological and management capabilities (Ernst and Kim, 2002).

(To follow: 1 para on the historic development of GPNs in Asia: Japan, US, etc.)

Government policies have fostered this integration into GPNs and have provided incentives, financial resources and public goods that have enabled local firms to reap the benefits of network participation. As a result, East Asia has emerged as the dominant global manufacturing base of the electronics industry, especially for assembly and component manufacturing.

Share of production, markets and exports

Table 1: Electronics Production and Markets : Top Countries, 2002[2]

Macro picture

Together, our five countries account for *one quarter* of world electronics production, but only about 16% or so of the global electronics market.

Imbalance between production and demand, with the exception of China →→ export platform production

BUT, the share of our five countries in the global electronics market is increasing

- recession in the US, Europe, and Japan

IBM: 21% of its sales revenues originate in Asia; Motorola > 15%

- lead user markets for telecommunications services & equipment (especially, Korea, China, Singapore)

Korea, Singapore: test-bedding
China: biggest market for telecommunications equipment (wired & wireless)

- sophisticated government procurement markets (singapore, Korea, China)
- very demanding private consumers (at least as long as the "credit card boom" lasted)

Disaggregated data

As usual, too much aggregation can mislead. Once we look at major *product markets*, the share of our five countries is substantially higher:

- CE (China, Korea), especially for digital AV equipment and mobile phone
- computers & peripherals (Taiwan, china)
- HDDs (Singapore triangle)
- communications (Korea, Taiwan, China)
- Most precision component manufacturing has moved to Asia.

Take semiconductors.

Table 2 Wafer Fabrication Moves to Asia-Pacific

(Quote latest figures from VLSI Research, in: Semiconductor Reporter)

[2] Annex contains all tables and figures

AP's share of worldwide foundry capacity, 2001: > 80%
(to follow: one para on historic stages of redeployment to Asia)

By country
Korea's dominant position in computer memories, flat-panel displays and in CDMA-based mobile phones is well known. …

Taiwan ranks as the #1 global world market supplier (2001) for 14 electronics products (**Table 3: Taiwan's Top Electronics Products (2001): ranking No.1)** That list includes for instance silicon foundry services (73% share in global production value), the provision of IC packaging and testing services (30.4%), notebook PCs (24%), and LCD monitors (41.1%). Equally important is that Taiwanese firms are market leaders in emerging growth markets related to wireless communication devices, leading the emerging market for wireless LAN (=local area networks, or WiFi). Taiwanese firms also are market leaders for digital AV equipment like CD-ROM disks and DVD disks, with much of these devices produced in low-cost locations in China. In addition, Taiwan ranks as the #1 global world market supplier for motherboards (1/3 of world exports), behind Intel; and the #3 provider in flat-panel displays (23 % share in global production value).

China is now # 3 worldwide, in terms of both electronics production and its market for electronics products. This represents a dramatic growth, compared to only a few years ago. Over the last few years, China has also become Asia's leading electronics exporting country[3]. Note however that roughly 60% of China's electronics exports originate from factories owned by Taiwanese companies. This figure indicates a dirty little secret of the global network economy: things are no longer as simple as we economists like to assume, with trade flows neatly identifiable with specific countries[4].

Estimate on export ranking order:
China (#3), Korea (#4), Taiwan (#5, slightly behind), Singapore (#7, behind Ireland, but before Mexico), Malaysia (#9).

Table 4: Asian Trade Specialization Profiles: RCA and Leading Export Products, 1993 - 1998
(We will cross-check with 2002 UN Trade Data Base Comtrade. Our data base currently covers 1998).

2. New Challenges

[3] The share of technology-intensive products (primarily electronics) in China's global exports has increased dramatically from 3% in 1985 to22% in 2000, making China the largest exporter of such products in the developing world (UNCTAD, 2003)
[4] An early empirical analysis of the impact of GPNs on trade patterns in Asia's electronics industry can be found in Ernst and Guerrieri, 1998.

This section highlights new challenges that have induced Asiars leading electronics exporting countries to attempt to upgrade its manufacturing as well as its innovative capabilities. These efforts are very serious. There are of course powerful incentives to pursue upgrading strategies: A company can reap vastly superior profit margins, the higher it moves up on the ladder to innovation (see **Table Innovation and Profits**). But these incentives have to be balanced against the cost of upgrading. Moving up to more complex and knowledge-intensive activities requires concerted efforts and massive investments to improve skills and innovative capabilities on the level of the firm, as well as significant improvements in industry-specific, regional and national production and innovation systems.

Nevertheless, there are powerful pressures to proceed with upgrading efforts. There is a growing recognition that there are simply no alternatives to innovation, as traditional strategies are insufficient to cope with four new challenges: the decreasing returns of export-led industrialization, the increase in the frequency and destructive power of external shocks, the dual shift in Asia's economic power structure, and a US-centric concentration of economic power and of the sources of innovation.

2.1. Decreasing returns to export-led industrialization

A consensus is emerging in Asia's successful exporting countries that improved innovative capabilities are required to cope with decreasing returns of export-led industrialization, and to cope with the impact of external shocks that appear to gain in frequency and destructive power. There is a widespread perception that export-led industrialization, based on integration into global production networks (GPNs), produces rapidly decreasing returns. Of particular concern is a declining capacity for employment generation. While after earlier downturns a substantial share of laid-off workers were re-hired, this no longer seems to be the case. In Malaysia's electronics industry, for instance, an estimated 150,000 to 165,000 jobs have been lost since the financial crisis (Ernst, 2003, in World Bank book, OUP). In Penang, almost two third of the retrenched workers in the electronics industry (ca. 16,000, primarily low-skilled, female production workers), have left the labor market, indicating a massive return of Malay females (in the 25-29 age range) to their villages (Too and Leng, 2002). And in Singapore, the share of employment in the electronics industry out of total employment has declined from 28% (1992) to 19% in 2002.

Another proxy for decreasing returns is a disturbing slow-down in productivity growth. In Penang, for instance, total factor productivity (TFP) of manufacturing declined by -0.5 **%** between 1995 and 1997, compared to an increase of 8.9% between 1990 to 1995 (State Government of Penang, 2001). In the electronics industry, TFP growth fell to 2% (from 14.1% during the earlier period) - hardly sufficient for an industry that is supposed to be the engine of upgrading[5].

[5] As for TFP growth for all of Malaysia, most estimates put it around 1 to 2 % p.a. (until 2000). This is way below the minimum TFP growth projected by the government of 3.2% (for the period 2001 to 2010), which is necessary, if Malaysia wants to achieve the projected growth rate of 7.5%. Compared with historical growth patterns of productivity in industrialized countries, such a massive slow-down in TFP

(To follow: more indicators on declining employment generation capabilities; slow-down of productivity growth; closing-down of factories by global brand leaders; footloose investment; limited local spill-overs, once global contract manufacturers take over factories from global brand leaders..)

2.2. External shocks

The perception of decreasing returns has been strengthened by recent external shocks like the financial crisis, recession, geo-political conflicts, and war[6]. Those shocks are man-made, and are an intrinsic element of globalization: they appear to gain in frequency and destructive power. We define "globalization" as the integration, across borders, of markets for capital, goods, services, knowledge, and labor (Ernst, 2003, in Sassen book, Princeton). Barriers to integration continue to exist of course in each of these different markets (especially for low-wage labor), so integration is far from perfect. But there is no doubt that a massive integration has taken place across borders that, only a short while ago, seemed to be impenetrable. This has increased the synchronization of economic activities, including that of financial crises and recessions. For instance, 82 financial crises have occurred worldwide between 1970 and 1996 (Eichengreen and Rose, 1998), indicating that little is exceptional about the 1997 Asian financial crisis, and that such crises may well re-occur..

In addition, Asia's rapid export-led industrialization is also exposed to natural shocks, due to environmental degradation and earthquakes. For instance, much of the production of key IT components (semiconductors, displays, storage devices) critically depends on uninterrupted access to filtered, ultra-pure water[7]. Taiwan is currently hit by one of the worst droughts in decades, yet its wafer fab cluster in Hsinchu, the largest worldwide (15 fabs producing $8.2billion worth of chips, i.e. 7% of the world's total) require uninterrupted water supply: each wafer fab roughly consumes up to 3 million gallons of ultra-pure water per day. Singapore, which heavily depends on water supply from Malaysia is periodically faced with similar emergencies. And Taiwan's earthquake on September 21, 1999, with a magnitude of 7.6 on the Richter scale, had a devastating effect on the global supply chain of semiconductors. Losses incurred by the wafer fabs in Hsinchu science park were estimated at about $ 1 billion, primarily due to the disruption of electric power supply. Electronics factories, and especially semiconductor fabrication lines, are extremely sensitive to power fluctuations, let alone full-scale blackouts lasting for days. At that time, Taiwanese wafer fabs accounted for more than 12 % of global fabrication capacity, which indicates how vulnerable to such disruptions the global semiconductor industry has become.

growth is certainly premature, in light of the thus far still limited progress in Malaysia's specialization by product and production stage.

[6] In the specialized literature on global supply chain management in Asia , a number of books and articles examine in quite some detail the disruptive potential of geo-poltical conflicts like the cross-Strait relations between China and Taiwan, the Korean conflict, the "war on terrorism" in Asia, and the impact of piracy on sea-borne trade in Southeast Asia.

[7] See the East-West-Center's new project on "Dirty Silicon - Developing Environmentally Friendly Information Technology Production Clusters in Asia".

Each of these shocks threatens to disrupt the region's integration into GPNs. Asia's globally integrated industrial clusters pay a high price for such disruptions: declining exports, excess capacity and price wars have periodically squeezed profit margins of Asian exporting firms. In many cases, this has led to a vicious circle of declining investment, down-sizing and mass lay-offs. More recently, the *SARS* epidemic has added further to this perception that something needs to change, and that innovation needs to complement industrial volume manufacturing to generate sustained economic development.

2.3. Asia's changing economic power structure

In addition, two important changes have occurred in Asia's economic power structure that are affecting the parameters of Asian development strategies: the erosion of Japan's role as the regional economic hegemon, and the ascent of China.

a) Japan's changing role

First, there is a widespread perception that Japan's role as the regional economic hegemon shows signs of decline. Asia now depends considerably less on Japan as a provider of capital, key technologies and development models, and this is true as well for the electronics industry. Hamilton-Hart (forthcoming) documents the withdrawal of Japanese corporate capital from Asia after 1997[8]. And Ernst (forthcoming) examines how the at least partial adaptation of Japanese production networks in Asia to the American model of IT-enabled outsourcing and share-holder capitalism has discredited the traditional Japanese development model with its focus on integrated hardware manufacturing.

However, one should obviously not exaggerate the decline of Japan's role for Asian electronics industries. Especially in electronics, Japanese firms continue to move their production facilities out of Japan, primarily to China, while maintaining operations in Southeast Asia[9]. Japanese firms also remain a major source of components and machinery for Asian electronics industries, **but their share in such imports appears to be declining** (*check with* JETRO, 2003). What matters is that important changes are occurring in the way Japanese firms organize their Asian production networks, and that this may change the parameters for Asian upgrading strategies in the electronics industry.

[8] This argument is based on Ministry of Finance data that do not include the quite substantial amounts of reinvestments of Japanese affiliates in Asia that take place without a capital transfer from Japan to the region. Earlier research by JBIC (Japan Bank for International Cooperation), the former Ex-IM Bank of Japan, and especially work by Shigeki Tejima demonstrates that, until around 2000, the declining FDI outflows from Japan to Asia reflected the relatively strong financial performance of Japanese affiliates especially in cars and electronic components. This has enabled local affiliates to increase reinvestments out of locally generated profits. It is unclear whether this is still the case.

[9] JETRO data for the first half of 2002 show Japanese outward manufacturing FDI to East Asia has increased by 3.8%, to the ASEAN4 by 15.7% (first increase since 1998), and to China by 44.8%. The large electronics conglomerates like Hitachi, Toshiba, NEC are attempting to rationalize their over-lapping Southeast Asian and China-related networks, consolidating large export platform mega-plants in one location. A typical example is Toshiba's new mammoth integrated production complex in Shanghai.

In the semiconductor industry, Japanese firms have started already in the mid-1990s to develop outsourcing arrangements and strategic alliances with Taiwanese firms (Ernst and Ravenhill, 1999). They are investing in R&D centers, both in China and Southeast Asia, where the focus now shifts from product customization and process adjustment to IC design and software services. Moreover, Japanese firms continue to play important role as a provider of management techniques for Asian suppliers[10].

b) China's ascent

A second important transformation of Asia's economic geography in the electronics industry is the new role played by China. Until the mid-1990s, four first-tier NIEs (Korea, Taiwan, Hong Kong, and Singapore), and two second-tier NIEs (Malaysia and Thailand), were considered to be the standard bearers of the so-called "East Asian Miracle". That changed however, once China emerged as a major market and manufacturing base for increasingly sophisticated industrial products. China's inward FDI during the first 10 months of 2002 was $ 46.4 billion (UNCTAD, 2003). Even if one assumes that "round-tripping"[11] constitutes 35% of inward FDI, China's actual FDI inflows would be $32 billion. This would still represent 80% of all FDI inflows to Asia, excluding Japan. This new wave of inward foreign direct investment (FDI) and the consequent integration into GPNs of new clusters in South and East China has generated fears of trade and investment diversion in the rest of Asia.

A vast pool of cheap labor allows China to continue to compete as a low-cost manufacturing base[12]. At the same time, however, China is distinguished by a broad base of accumulated capabilities in R&D, developed in the Chinese Academy of Science and related institutions, and in the defense sector. It would thus be a great mistake to view China only as the cheap-labor workshop for the global electronics industry. China's new attractiveness results from a combination of five developments: a booming market for IT products and services, when the rest of the world is in recession; China's unlimited supply of low-cost IT skills; abundant land and a rapidly improving infrastructure; a massive rush of capital flows into China; and, catching this opportunity, support policies pursued by the central government, as well as regional and local authorities to develop local capabilities and to rely on FDI as an accelerator of industrial upgrading.

The share of foreign-invested affiliates in technology-intensive industries (primarily electronics) has risen from 59% in 1996 to 81% in 2000. In the electronics industry, leading global market leaders (whether from the US, Japan, Europe, or Korea), their global suppliers from Korea and Taiwan, and, more recently, the leading U.S. contract manufacturers have identified China as a priority investment target. The penetration of FDI is particularly pronounced in three sectors: electronic components (especially semiconductors), computers, and telecommunications. Until 1999, investment in Chinar's

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[10] Among the many fascinating examples is Namtai…

[11] Actual inward FDI into China falls short of official estiamtes owing to the prevalence of "round tripping": lower tax rates on foreign capital create an incentive for domestic entrepreneurs to move money offshore (e.g., to Hong Kong and the Virgin Islands) and introduce it as FDI.

[12] An estimate based on 2000 data indicates that broadly defined unemployment in China has reached 207 million, or 29.1% of the total active population (Imai, 2002: p.33)

semiconductor industry lacked woefully behind similar investments in Korea and Taiwan. The turning point came in 2000. During that year, the Chinese government apparently made a strategic decision to rely on FDI to accelerate the development of this industry. Lavish tax and tariff incentives, and the prospect of a burgeoning market have induced global industry leaders from the US, Taiwan, and Japan to announce a battery of large investment projects worth around $ 15 to 20 billion. For US FDI in semiconductors, for instance, China has become the second most important recipient, after Singapore, overtaking Malaysia, which was the main recipient in 1996 (Malaysia Ministry of Finance data, quoted in Takeuchi, 2001).

In computers, Taiwanese companies that supply global US brand leaders have played an important pioneering role in integrating China into GPNs. Since the early 1990s, they have continuously moved production from Taiwan to China. American global market leaders in computers and related peripheral equipment followed suit, in turn attracting a massive inflow of investments by US-owned global contract manufacturers (Ernst, 2003, World Bank book, OUP). The result is that "Greater China" (i.e. China plus Taiwan) today has become the predominant global supply base for computers.

As for telecommunications and networking equipment, major global market leaders, like Motorola, Cisco, Nokia, Alcatel, Siemens, Ericsson, and Philips-Sony have all initiated significant new investment projects in China. Motorola for instance counts on continuous rapid growth of the China market to reduce the negative impact of the current recession. In 2000, China accounted for 12% of Motorola`s global sales, generating $ 4.5 billion of revenue. The company plans to double its China investment from $ 5 bn in 2001 to $ 10bn in 2005, which would give rise to a massive expansion of manufacturing investment. But China is also expected to play an important role for Motorola's long-term strategy. By providing access to the world`s largest pool of relatively lower-cost IT skills, the company expects to enhance its innovation capabilities.

In short, emergence of China as a new force in the global electronics industry poses a serious challenge for Asian electronics industries that continue to focus on volume manufacturing. But the new challenge from China could also be a "blessing in disguise", catalyzing for serious upgrading efforts. Furthermore, China's huge potential market for electronic products and services provides new trade and investment opportunities for Asian firms[13].

2.4. Global concentration of economic resources

As a result of the "New Economy" boom of the 1990s, "the world is more US-centric now than it has ever been" (Stephen Roach, chief economist of Morgan Stanley, at the World Economic Forum 2003). There is clear evidence that the concentration of economic power has substantially increased since the late 20th century, first through mergers & acquisitions, fueled by the "New Economy" boom, and now through consolidation imposed by the recession. This has benefited primarily US corporations. In addition, the sources of innovation remain highly concentrated, centered primarily on the

[13] *Quote recent trade and investment data for Taiwan, Korea, Singapore, and Malaysia*

U.S. 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). 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[14]. 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).

Concentration in the electronics industry is high and keeps rising in important sectors (Ernst, 2002, IEBM: 326 and 327). In terms of market shares, both computer operating systems and microprocessors are each overwhelmingly dominated by one company, Microsoft and Intel respectively. Concentration is also substantial for high precision key components that are critical for architectural design and performance features, such as DRAM, advanced displays and hard disk drives. Concentration has also drastically increased in the PC industry, an industry which only a decade ago was hailed by neo-liberals as a holy grail of free competition (Gilder 1988). The top two global market players –Dell and Hewlett Packard – have captured almost 70 per cent of PC unit growth worldwide. And as a result of the downturn in the global IT industry since late 2000, concentration has also dramatically increased in the global electronics manufacturing services industry, as well as for telecommunications and networking equipment.

IT-based global networking practices have contributed to this growing concentration of control over critical economic resources (Ernst, 2002, forthcoming in Sassen book, Princeton). A GPN integrates diverse network participants who differ in their access to and in their position within such networks, and hence face very different opportunities and challenges. These networks do not necessarily give rise to less hierarchical forms of firm organization (as predicted for instance in Bartlett and Ghoshal, 1989, and in Nohria and Eccles, 1993). GPNs typically consist of various hierarchical layers, ranging from network flagships that dominate such networks, due to their capacity for system integration (Pavitt, 2002), down to a variety of usually smaller, local specialized network suppliers.

By establishing hierarchical, flagship-dominated global production networks, a global brand leader ("system integrator") can in principle expand his control over scarce resources and capabilities well beyond those resources and capabilities that, from an accounting perspective, lie directly under its management control. The strategy of the flagship company thus shapes the growth, the strategic direction and network position of lower-end participants, like specialized suppliers and subcontractors. The latter, in turn, " have no reciprocal influence over the flagship strategy" (Rugman and DrCruz, 2000, 84).

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[14] 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)

The flagship derives its strength from its control over critical resources and capabilities that facilitate innovation, and from its capacity to coordinate transactions and knowledge exchange between the different network nodes.

There are widespread fears that the spread of GPNs may constrain Asia's attempts to move from upgrading its manufacturing capabilities to upgrading its innovative capabilities. However, as I will argue in the next section, the emerging global network economy will provide ample opportunities for new entrants in the global innovation race, despite the very high and increasing global concentration. This reflects an important puzzle of the global electronics industry: even when concentration is very high, this industry fails to act like a stable oligopoly, due to the rapid pace of change in technology and markets (Ernst, 2002, The International Encyclopedia of Business and Management (IEBM)).

3. Opportunities: New Mobility of Knowledge in the Global Network Economy

3.1. Asia's Catching-up in innovation

Despite the new challenges that are faced by Asian electronics industries, there are signs of a gradual strengthening of Asia's 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 manufacturing capabilities. Take the following illustrative examples.

Chip design, a process that creates the greatest value in the electronics industry, has experienced a massive geographic dispersion to Asia: without 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 (Ernst, 2003, Pavitt conference). Taiwan has emerged as a primary new location for chip design: five of the top 20 worldwide fabless companies are from Taiwan; and two Taiwanese design houses have moved up to the number 5 and 6 spot, capturing 16% of total fabless revenues. 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 India, as well as in Singapore and Malaysia.

Patents, a widely used proxy for innovative capabilities, also indicate substantial progress. Take Taiwan, which did not show up in 1990 among the 10 top countries, in terms the number of patents granted in the US. Ten years later, in 2000, Taiwan was the fourth largest country (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. In the case of Taiwan, it has been argued that, despite this impressive quantitative performance, major weaknesses remain (Shang-Jyh Liu, 2001): there is a focus on gradual improvements of manufacturing processes, and most patents can only be used as tools for self-protection or cross-licensing. In terms of the CHI citation index, discussed above, Taiwan's patents are not pioneering patents that are connected with important inventions and discoveries.

But the use of patenting as a bargaining chip may actually not indicate a weakness. In the electronics industry, it may be a perfectly rational strategy. For that industry, a major study, published by the National Bureau of Economic Research (Cohen, Nelson and Walsh, 2000: 24 and 26), indicated that, "the larger, more patent intensive firms are more likely to use …(patents)… to strengthen their positions as players in cross-licensing negotiations. …(T)he size and quality of a firm's patent portfolio … affects the terms of trade between rival technologies and its own." And Kingston (2001: 408) emphasizes that in the electronics industry it is an established practice to use patents as a "trading currency". For Asian electronics that want to participate in the global innovation arms race (Baumol, 2002), it is necessary to develop broad-based patent portfolios to avoid being denied the use of critical inventions by global market leaders like Intel.

During recent interviews with global electronics companies, I found a broad consensus that, in areas like digital consumer devices and mobile communications systems, the epicenter of innovation is likely to gradually move to Asia, especially greater China. There was also a widespread perception that this may include the definition of product and system standards. In consumer electronics, an example are joint efforts by China and Taiwan to develop a new video-disk technology format, called enhanced versatile disk (EVD) 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[15]. 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, an important example are China's attempt to develop an alternative third generation (3G) digital wireless standard, called TD-SCDMA (time-division synchronous code-division multiple access)[16], for which it received approval by the International Telecommunications Union (ITU) in August 2000. The 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, LG, and Taiwanese ODM suppliers (January 2002), a joint venture with Philips and Samsung (December 2002), and a licensing agreement with STMicroelectronics that will provide the Chinese company with access to critical design building blocks (Semiconductor Business News, January 17, 2003).

Of course no serious observer would claim that Asia, or "Greater China" for that matter, will overtake the US, as well as Europe and Japan, as the global leading centers of innovation. We are observing an incremental process of change, but nevertheless an important one. It is no longer possible to take for granted Vernon's assumption

[15] Two major licensing groups dominate the DVD standard, and both charge substantial royalty fees: the DVD6C group (i.e., Hitachi, Matsushita, Mitsubishi, Toshiba, JVC and AOL Time Warner), and the 3C group (Philips, Sony, and Pioneer).

[16] The two main competing 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).

underlying his product life cycle theory that innovations necessarily emerge first in the US or Europe. It is now much more difficult to predict when and where innovations will occur. As observed in Yusuf (2003), innovations are springing up at an increasing number of locations - albeit in global terms the number of these locations is still limited. In some cases, Asia may actually be the source of innovations. In a few cases, it may also shape global standards.

This surge in Asian innovative capabilities may actually be less surprising than it may look at first sight. It reflects the new mobility of knowledge in the emerging global network economy that is broadening the sources of knowledge that Asian economies can access. This new mobility of knowledge results from a combination of three inter-related transformations that are blurring the traditional boundaries between manufacturing and innovation (Ernst, forthcoming, Sassen book Princeton):

- vertical specialization ("outsourcing" in industry parlance) no longer is restricted to production (of goods and services), but covers all stages of the value chain, including R&D and new product development;
- the reintegration of geographically dispersed specialized supply bases into multi-layered "global networks of networks" that encompass production, supply chain management as well as product development and design;
- and the increasing use of digital information systems (DIS) to manage these diverse networks to enhance not only information exchange, but also the sharing and joint creation of knowledge.

3.2. Vertical specialization

Vertical specialization is a powerful driver of the emerging global network economy. This reflects the growing complexity of competition, especially in knowledge-intensive industries like electronics (Ernst, 2002, The International Encyclopedia of Business and Management (IEBM)). Intense price competition needs to be combined with product differentiation, while continuous price wars erode profit margins. Of critical importance, however, is speed-to-market: getting the right product to the largest volume segment of the market right on time can provide huge profits. Being late can be a disaster, and may even drive a firm out of business. The result has been an increasing uncertainty and volatility, and a destabilization of established market leadership positions.

This growing complexity of competition has changed industrial and firm organization. No firm, not even a dominant market leader, can generate all the different capabilities internally that are necessary to cope with the requirements of global competition. Competitive success thus critically depends on vertical specialization: a capacity to selectively source specialized capabilities *outside* the firm. These capabilities can range from simple contract assembly to quite sophisticated design capabilities.

The electronics industry has become the most important breeding ground for this new industrial organization model (**Table 5: Vertical Specialization in Electronics Industry)** Over the last decades, an erstwhile vertically integrated industry has been segmented into closely interacting horizontal layers (Grove, 1996). Until the early 1980s, IBM personified 'vertical integration': almost all ingredients necessary to design, produce and commercialize computers remained internal to the firm. This was true for semiconductors, hardware, operating systems, application software, as well as sales and distribution.

Since the mid-1980s, vertical specialization became the industry's defining characteristic. An important initial catalyst of vertical specialization was the availability of standard components, which allowed for a change in computer design away from centralized (IBM mainframe) to decentralized architectures (PC, and PC-related networks). Most activities that characterized a computer company were now being farmed out to multiple layers of specialized suppliers, giving rise to rapid market segmentation and an ever finer specialization within each of the above five main value chain stages. This has culminated in the co-evolution of complex, globally organized product-specific value chains (for example, for microprocessors, memories, board assembly, PCs, networking equipment, operating systems, applications software, and sales & distribution). GPNs compete with each other in each of these value chains, but they may also cooperate.

Vertical specialization has also fundamentally transformed the semiconductor industry (**Table 6: Vertical Specialization: Semiconductor Industry, EWC talk)**. This industry consists of six main stages: system specification, process technology, design implementation, fabrication, packaging & testing; and materials & production equipment. Initially, all of these six stages took place in one firm, such as IBM (a captive semiconductor producer), or Intel (a so-called merchant firm). Innovation proceeded *sequentially* through collaboration among specialized divisions within the firm. Since the mid-1980s, vertical integration gave way to a process of progressive vertical specialization. This process has two dimensions: *organization* (a move from *integration* to *disintegration*) and *location* (a move from *geographic concentration* to *dispersion*).

Certain activities have moved out to specialized suppliers (*disintegration*). Over time there has been a parallel process of geographic *dispersion* from the initial centers of excellence to new locations, with new suppliers emerging in Asia. The first stages to move to Asia were chip packaging and testing (Ernst, 1983), followed by certain aspects of design implementation (especially for ASIC design), and fabrication (memories and foundry services). This process of geographic dispersion has been accelerated over the last few years, especially for fabrication, but also for materials and manufacturing equipment, and for the development of process technology. As mentioned before, there are also now a few examples of system specification having moved to Asia.

It is important to emphasize that vertical specialization applies as much to research and innovation as to manufacturing. Take IC design. Until the mid-1980s, IC producers 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 focus on specific niche markets for integrated circuits (ICs).

More recently, a second stage of vertical specialization has occurred within the process of IC design itself. A primary driver has been a widening design productivity gap in ICs (see **Figure 1: Widening Design Productivity Gap in Integrated Circuits)**. While the productivity of IC fabrication over the last twenty years has seen a 58% compounded annual growth, the productivity of chip design has dramatically lagged behind, with a 21% compounded annual growth. As a result, the number of available transistors has grown faster than the ability to design them meaningfully. However, investment in process technology has by far outpaced investment in design technology. And, most disturbingly, the cost of design has grown exponentially, reflecting increasingly complex design requirements[17].

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 IC design (**Table 7: Annual Cost of Employing a Chip Design Engineer)**. In light of the fact that the annual cost of employing a chip design engineer in Asia is around 10 % of the cost in Silicon Valley, it is hardly surprising to find that chip design is being relocated to some of the leading IT clusters in the Asia-Pacific region 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[18] 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 IC. Instead, many companies are contributing, based upon their specific areas of expertise. This leads to the development of global electronic design networks (GEDNs) that link together individual design houses, the licensors of specific design building blocks (the so-called "silicon intellectual properties", SIPs), design service providers, foundries, design tool vendors, design departments of large electronics systems and brand name companies, etc that are all contributing to the complete IC design solution.

Progressive vertical specialization may facilitate the implementation of innovation strategies in Asia. The dual process of organizational disintegration and geographic dispersion may open up new entry possibilities for specialized suppliers. Take again chip design. As global specialized suppliers proliferate across all stages of the semiconductor value chain, from assembly and test, to wafer fabrication, design tools, and different stages of design, this opens up new opportunities for Asian countries to develop their own chip design industries. Electronic design houses in country A can now rely on access to specialized silicon foundry suppliers in countries B and C, as well as on specialized suppliers of assembly & testing services in countries B, C, D, and E. Equally important, it is now possible for design houses in country A to gain "design-ins" with system

[17] Design costs massively outpace the cost of chip manufacturing. Manufacturing costs for chips, the so-called non-recurring engineering costs that cover masks and probe card, are reaching $ 1 million. However design-related NREs routinely reach tens of millions of dollars, with design shortfalls being responsible for massive corrections in fabrication that multiply manufacturing NRE (International Technology Roadmap for Semiconductors, 2001, p.81).

[18] (SOC) design integrates the traditional microprocessor, memories and peripherals - in other words the whole system - on a single piece of silicon.

companies that are located in large markets. As demonstrated above, significant new test-bedding markets for digital consumer devices as well as mobile communications systems have emerged in Asian countries, especially Korea, Singapore and Greater China.

3.3. Reintegration: global networks of networks

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. The necessary complement to vertical specialization, and the resultant geographic dispersion, are large global corporations (the network flagships) that can act as system integrators for the diverse, multi-layered global networks of networks that have evolved as a result of vertical specialization (see also Pavitt, 2002).

A defining characteristic of the global network economy is the transition from vertically integrated 'multinational corporations' (MNCs), with their focus on stand-alone, equity-controlled overseas investment projects, to flagship-dominated multi-layered "global networks of networks" that encompass production, supply chain management as well as product development and design. This contrasts with centuries of economic history where MNCs were the main drivers of international production (for example, Braudel, 1992; Wilkins, 1970).

The concept of global production networks (GPNs) highlights two important dimensions: the transition from intra-firm to inter-firm transactions and forms of coordination, and the increasing scope of network activities (**Figure 2: The Nodes of a Global Production Network).** A GPN links together the flagship's own subsidiaries, affiliates and joint ventures with its subcontractors, suppliers, service providers, as well as partners in strategic alliances (e.g., Ernst, 1997). These arrangements may, or may not involve ownership of equity stakes. A network flagship like IBM or Intel breaks down the value chain into a variety of discrete functions and locates them wherever they can be carried out most effectively, where they improve the firm's access to resources and capabilities and where they are needed to facilitate the penetration of important growth markets.

The main purpose of these networks is to provide the flagship with quick and low-cost access to resources, capabilities and knowledge that are complementary to its core competencies. In other words, transaction cost savings matter. Yet, the real benefits result from the dissemination, exchange and outsourcing of knowledge and complementary capabilities. **Figure 3 (Dell's Global Production Network)** illustrates the complex combinations of physical flows (including products and services) and information flows and knowledge exchange that bind together the participants of Dell's GPN. The architecture of this network reflects the peculiar strategic priorities of the network flagship: Dell's focus is on time compression in supply chain management and on rapid adjustment to changing customer requirements[19].

[19] Within the same product market, HP's different strategy priorities, especially its focus on innovation, gives rise to different network architectures.

We need to add a second level of complexity: most of the nodes of the GPN of a particular flagship, like Dell, simultaneously participate in multiple, other networks and/or act as flagships to other networks. For instance, a component supplier like Intel, one of the most powerful players in this industry, is the flagship of multiple specialized GPNs. Simultaneously, it participates in multiple other networks established by global brand leaders for digital computing, communication and consumer equipment and systems.

Until recently, these fundamental changes in the organization of international production have been largely neglected in the literature, both in research on knowledge spill-overs through FDI, and in research on the internationalization of corporate R&D. This is now beginning to change. There is a growing acceptance in the literature that in order to capture the impact of globalization on industrial organization and upgrading, the focus of our analysis needs to shift away from the industry and the individual firm to the international dimension of business networks (for example, Bartlett and Ghoshal, 1989; Gereffi and Korzeniewicz, 1994; Ernst, 1997; Rugman and DrCruz, 2000; Birkinshaw and Hagstrшm, 2000; Borrus et al., 2000; Pavitt, 2002; Ernst and Ozawa, 2002). A focus on the evolution of cross-border corporate networks allows us to identify what is 'new' about the global network economy.

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. And leading growth economists (for example, Grossman and Helpman, 2002) are basing their models on a systematic analysis of global sourcing strategies.

Our model of GPNs builds on this work, but uses a broader concept that emphasizes three essential characteristics: i) *scope*: GPNs encompass all stages of the value chain, not just production; ii) *asymmetry*: flagships dominate control over network resources and decision-making[20]; and iii) *knowledge diffusion*: the sharing of knowledge is the necessary glue that keeps these networks growing.

A focus on international knowledge diffusion through an extension of firm organization across national boundaries distinguishes our concept of GPN from network theories developed by sociologists, economic geographers and innovation theorists that focus on localized, mostly inter-personal networks (for example, Powell and Smith-Doerr, 1994). The central problem of these theories is that industries now operate in a global rather than a localized setting (Ernst et al., 2001). Important complementarities exist however with work on global commodity chains (GCC) (for example, Gereffi and Korzeniewicz, 1994).

[20] See our discussion in 2.4.

A primary concern of the GCC literature has been to explore how different value chain stages in an industry (i.e. textiles) are dispersed across borders, and how the position of a particular location in such GCC affects its development potential through access to economic rents (for example, Gereffi and Kaplinsky, 2001; Henderson et al. 2001)[21]. Strong complementarities also exist with research on computer-based flexible information infrastructures that frequently uses the terms 'extended enterprise' or 'virtual enterprise', where the first stands for more durable network arrangements, while the latter for very short-term ones (for example, Pedersen et al. 1999).

By highlighting the dynamics of network evolution, our approach complements the transaction cost approach to networks and vertical disintegration, which centres on the presumed efficiency gains from these organizational choices (for example, Williamson, 1985; Milgrom and Roberts, 1990). Our approach attempts to bring back into the analysis market structure and competitive dynamics, as well as the role played by knowledge and innovation.

3.4. Digital information systems and knowledge diffusion

There is a growing recognition in the literature on corporate networking practices that the increasing use of digital information systems (DIS) to manage these diverse networks may increase the mobility of knowledge. GPNs expand inter-firm linkages across national boundaries, increasing the need for knowledge diffusion, while DIS enhance not only information exchange, but also the sharing and joint creation of knowledge.

Global corporations (the "network flagships") construct these production networks to gain quick access to skills and capabilities at lower-cost overseas locations that complement their core competencies. Flagships need to transfer technical and managerial knowledge to local suppliers. This is necessary to upgrade the suppliers' technical and managerial skills, so that they can meet the technical specifications of 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).

This new mobility of knowledge is made possible by important transformations in the use of DIS as a management tool. From a machine to automate transaction processing, the focus of DIS has shifted to the extraction of value from information resources, and then further to the establishment of Internet-enabled flexible information infrastructures that can support the extraction and exchange of knowledge across firm boundaries and national borders. A combination of economic and technological developments is responsible for this transformation.

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[21] Unfortunately, no one has as yet come up with a convincing and robust set of indicators. How should academic researchers, even with the best possible funding, be able to measure distribution of rents across borders, when global flagships like Enron and telecom majors excel in the development of sophisticated off-balance-sheet financial techniques and transfer pricing?

a) Economic drivers

On the economic side, vertical specialization, particularly pronounced in the electronics industry, poses increasingly complex information requirements (e.g., Chen, 2002; Macher, Mowery and Simcoe, 2002). As firms now have to deal with constantly changing, large numbers of specialized suppliers, they need flexible and adaptive information systems to support these diverse linkages. These requirements became ever more demanding, as flagships attempt to integrate their dispersed production, knowledge and customer bases into global and regional networks. DIS now need to provide new means to improve global supply chain management and speed-to-market. DIS also need to provide for effective communication between design and manufacturing, and for the exchange of proprietary knowledge. The semiconductor industry provides examples for both developments: vertical specialization gives rise to the separation of design ("fabless design") and manufacturing ("silicon foundry"). This creates very demanding requirements for knowledge exchange between multiple actors at distant locations, say a design house in Silicon Valley and a silicon foundry in Taiwan's Hsinchuh Science Park. Vertical separation of design and production of semiconductor devices in turn has created a vibrant trade in "intellectual property rights" among specialized design firms that create, license and trade "design modules" for use in integrated circuits.

In addition, far-reaching changes in work organization have fundamentally increased the requirements for information management and for the exchange of knowledge (e.g., Ciborra et al, 2000). The transition from Fordist "mass production" to "mass customization" requires a capacity to constantly adapt products or services to changing customer requirements, "sensing and responding" to individual customer needs in real time (Bradley and Nolan, 1998). This necessitates dynamic, interactive information systems, and a capacity to rapidly adjust the organization of firms and corporate networks to disruptive changes in markets and technology. Third, real-time resource allocation, performance monitoring and accounting became necessary, due to the short-term pressures of the financial system (quarterly reports) and due to the shortening life cycles of products and technologies. Fourth, to cope with ever more demanding competitive requirements, firms have to continuously adapt their organization and strategy, hence the demand for flexible DIS.

b) Technology drivers

On the technology side, the rapid development and diffusion of cheaper and more powerful information and communication technologies (e.g., Sichel. 1997, and Flamm, 1999) has considerably reduced transaction costs. In addition, the move towards more open standards in DIS architecture (UNIX, Linux, and HTML) and protocols (TCP/IP) enabled firms to integrate their existing intranets and extranets[22] on the Internet, which, by reducing cost and by multiplying connectivity, dramatically extended their reach across firm boundaries and national borders.

[22] An "intranet" is defined as a private network contained within an organization (a firm) that consists of many inter-linked LANs (= local-area networks). Its main purpose is to share company information and computer resources among employees. An "extranet" in turn is a private network that links the flagship via conventional telecommunications networks with preferred suppliers, customers and strategic partners.

Compared to earlier generations of DIS, the Internet appears to provide much greater opportunities to share knowledge with a much greater number of people faster, more accurately, and in greater detail, even if they are not permanently co-located (Ernst, 2000, Lundvall and Smith book, Elgar). The most commonly used technologies today facilitate *asynchronous* interaction, such as e-mail or non-real time database sharing. But as data transfer capacity ("bandwidth") increases, this is creating new opportunities for using technologies that facilitate *synchronous* interaction such as real-time data exchange, video-conferencing, as well as remote control of manufacturing processes, product quality and inventory, maintenance and repair, and even prototyping. This has created new opportunities for extending knowledge exchange across organizational and national boundaries, further magnifying the scope for vertical specialization. Equally important, wireless Internet-based technologies have increased the mobility of DIS.

c) Impacts on knowledge diffusion

The transition to Internet-based information systems can drastically accelerate speed-to-market by reducing the time it takes to transmit, receive, and process routine business communications such as purchase orders, invoices, and shipping notifications. There is much greater scope for knowledge management: documents and technical drawings can be exchanged in real time, legally recognized signatures can be authenticated, browsers can be used to access the information systems of suppliers and customers, and transactions can be completed much more quickly. In addition, the Internet and related organizational innovations provide effective mechanisms for constructing flexible infrastructures that can link together and coordinate knowledge exchange between distant locations **(**Pedersen et al, 1999; Antonelli, 1992).

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. In addition, there has been a gradual reduction of constraints to the exchange of tacit knowledge. 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 (Jшrgensen 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", there is no doubt that the use of DIS to manage GPNs can enhance the sharing and joint creation of knowledge among multiple network participants at distant locations. This new mobility of knowledge provides new opportunities for Asian upgrading strategies in the electronics industry.

4. Asian Upgrading Strategies in the Electronics Industry

Asia's leading electronics exporting countries have implemented diverse upgrading strategies. The diversity of upgrading strategies reflects substantial differences in the product mix, as well as in the structure and development stage of the above electronics industries; it also reflects differences in the competitive dynamics across product markets. It would thus be a great mistake to assume that "one-size-fits-all" solutions can succeed: what works in one country will not necessarily work in another.

To highlight the diversity of upgrading strategies, I address two questions: How do Korea, Taiwan and Singapore (Asia's first-tier newly industrializing economies) and Malaysia (a second-tier NIE) differ in their strategies to move beyond low-cost manufacturing? And, second, what are distinguishing features of China's upgrading prospects as a "late-latecomer"? We conclude by highlighting some generic policy implications.

4.1. Diverse strategies to move beyond low-cost manufacturing

A common feature of Korea, Taiwan, Singapore and Malaysia is that low-cost manufacturing based on cheap labor has run its course. This sets the above four countries apart from China. Manufacturing will of course remain an important source of economic growth. Yet, all of these four countries are keen to move beyond volume manufacturing. Obviously, this change in strategy has to occur gradually, with an initial focus on niche markets. Building on existing strengths in volume manufacturing, *upgrading* requires the development of new skills and capabilities in product design and development, as well as in "embedded" software, system-on-chip (SOC) design, IPR trade, system integration, and in the management of resources, supply chains and customer relations. Of particular importance is the development of knowledge-intensive support services that are essential for all four upgrading strategies.

Important differences distinguish upgrading strategies in the above four countries that reflect historic differences in the development trajectories of their electronics industries. Korea's electronics industry has focused on the mass production of a narrow mix of own-brand-name consumer products and general-purpose high-precision components (like computer memories and displays). Taiwan's strategy, on the other hand, has focused primarily on supplying global brand leaders through OEM (original equipment manufacturing) or ODM (original design manufacturing) contracts, with a focus of improving process specialization and efficiency. A third trajectory can be found in Singapore and Malaysia. Both countries have relied heavily on inward foreign direct investment (FDI) by global corporations that act as flagships of global production networks (GPNs). Singapore's traditional role was to compete as a high quality, low-cost manufacturing base for GPNs, providing "a competitive and safe haven for manufacturing and a gateway to Asian markets." (Economic Review Committee, 2002a: 22). Malaysia has tried to reap as many benefits as possible from the fortuitous tailwind of FDI that swept into Southeast Asia since the late 1970s. The guiding principle has been "outward industrialization", subordinated to the needs of Japanese, American and Taiwanese global network flagships, and focusing on low-end assembly operations.

(a) Malaysia[23]

In Malaysia, the Second Industrial Master Plan (IMP2) (Ministry of International Trade and Industry, 1996) signaled a fundamental change in the country's industrialization strategy, away from assembly-based "outward industrialization" to value chain-based manufacturing, from sector-based to cluster-based development, and from performance targets to productivity-driven growth. The strategy is defined by two key concepts: "manufacturing ++" and "cluster-based development". In line with Porter (1990), "manufacturing ++" highlights activities at both ends of the value chain, i.e. R&D and engineering, and in-bound logistics on the one hand, and outbound-logistics and sales & marketing, on the other hand. It is argued that a move into knowledge-intensive support services like product development, process engineering, supply chain management, and some select areas of R&D will enhance local value-added and productivity. "Cluster-based development" implies that, based on existing strengths especially in components and semiconductors, developing a dense web of domestic linkages will enhance value - added and deepen domestic capabilities.

IMP2 highlights four specific objectives: i) foster the growth of leading local companies (Malaysian brands); ii) reduce dependence on input imports; iii) strengthen agglomeration economies by developing "Integrated Manufacturing Centers" (IMC) for global network flagships; and iv) develop cross-border clusters. Of these, the first two objectives are problematic, while the last two indicate a move in the right direction[24]. Take recent developments in the Penang cluster where an attempt is made to combine the third and the fourth objective of the IMP2. Rather than just giving in to requests for improved incentives by foreign companies, the state government pursues a more selective approach: incentives are explicitly linked with the promotion of "integrated manufacturing centres" (IMC).The goal is to induce global flagships to move to Penang an "entire chain of operations for a particular product". It is expected that this should enable the Penang cluster to upgrade from mere assembly and testing to knowledge support services, like sales and marketing, adaptive process engineering and tooling, financial planning, and, eventually parts of R&D like design and development (D&D).

In short, with the Penang Skills Development Centre, with its second industrial master plan, and with the Bill of Guarantees (developed for its Multimedia Super Corridor), Malaysia has developed one of the most aggressive sets of upgrading incentives for private companies (both foreign and domestic)[25]. And yet, despite such policies, low-end

[23] Based on Ernst (2003, World Bank book, OUP)

[24] The first objective represents an outdated concept of industrial upgrading that assumes a *fixed* sequencing pattern from low-end, assembly-type subcontracting to "original brand name" (OBM) manufacturing (for a typical example, see Hobday, 1995). We now know that the transition to OBM is extremely difficult - even Taiwan´s Acer group has had only limited success (Ernst, 2000). The limited achievements of the "Proton City cluster" in automobiles also indicate that this objective may be unrealistic. As for the second objective, much depends on whether the country succeeds in finding the right balance between reaping the benefits of foreign input imports (as described in Rodrik, 1999) and the development of local backward and forward linkages. Hirschman (1956) in fact emphasizes the need to combine both effects.

[25] According to the Multimedia Development Corporation (2002), these incentives include commitments "to provide a world-class physical and information infrastructure; to allow unrestricted employment of

assembly operations continue to dominate. Most importantly, Malaysia has failed to develop a sufficiently diversified and deep industrial structure, to induce a critical mass of corporate investment in specialized skills and innovative capabilities. There is a growing recognition that lavish tax incentives and massive investment in infrastructure are insufficient to bring about the development of dynamic clusters. Recent strategic documents emphasize that the key to success are incessant efforts on a massive scale to continuously upgrade existing skills and capabilities, and to extend them into new areas like photonics, embedded software and chip design (National Information Technology Council, 2002).

(b) Singapore

Two peculiar features characterize the development of Singapore's electronics industry: its heavy dependence on foreign investment, and one of the earliest attempts in Asia to move beyond low-cost manufacturing by "riding the waves" of competing American and Japanese GPNs (e.g., Wong, 2000). Government policies have focused on infrastructure support, manpower development and incentives to attract investments into higher value-added manufacturing activities, "with scant regards for nationality of equity ownership." (Wong et al, 1997).

Equally important, the government has put in place a broad array of policies to promote the development of domestic small-and medium-sized enterprises in critical electronics supporting industries like plastic molding, metal stamping, tool and die making, precision parts and components, electroplating and finishing, mold making, jigs and fixtures, casting, printed circuit board assembly, and industrial automation equipment. An important institutional innovation has been the establishment, in 1986, of the Local Industry Upgrading Program (LUP), administered by the Economic Development Board (EDB) to forge closer ties between local enterprises and global network flagships, thereby exposing local enterprises to leading-edge management procedures and technological knowledge (EDB, 1993). Recently, Singapore has amended this policy with a new program to promote local information service suppliers, called "Infocomm Local Industry Upgrading Programme" (iLIUP). A typical example is the iLIUP partnership agreements that link Software AG, the German vendor of XML (=extensible markup languge) software, with specialized Singaporean solution providers[26] to develop customized XML-based business solutions for foreign affiliates and Asian companies. To make this network work, Software AG has brought in a global supplier of training programs for XML and related technologies, called Genovate Solutions. The latter

local and foreign knowledge workers; to ensure freedom of ownership by exempting companies with MSC Status from local ownership requirements; to give the freedom to source capital globally for MSC infrastructure, and the right to borrow funds globally; to provide competitive financial incentives, including Pioneer Status (100 percent tax exemption) for up to ten years, or an investment tax allowance for up to five years, and no duties on the importation of multimedia equipment; to become a regional leader in Intellectual Property Protection and Cyberlaws; to ensure no censorship on the Internet; to provide globally competitive telecommunications tariffs; to tender key infrastructure contracts to leading companies willing to use the MSC as their regional hub; and to provide a high-powered implementation agency to act as an effective one-stop super shop."

[26] These Singaporean solution suppliers focus on enterprise resource planning (ERP), system management, network security, network knowledge management and a variety of Internet-based application services.

company is responsible for establishing and running an XML Academy in Singapore that serves the Asia-Pacific region, training enterprises and individuals on XML, SAP, Java, Oracle, Linux, Web Logic and other enterprise software programs.

In addition, the Singapore Government, through its investment arm Temasek Holdings, has attempted to develop innovative domestic electronics firms that would be strong enough to compete globally. Temasek for instance invested heavily in the growth of companies such as Chartered Semiconductor (for silicon foundry services) and Singapore Technologies Assembly & Test Services (STAT, for the assembly and testing of integrated circuits). However, this strategy does not seem to be working. Chartered has been performing badly. Chartered, ranked a distant third behind Taiwan TSMC and UMC in the global market for made-to-order chips, has had its nineth straight quarterly loss as of 31 March 2003. The government is now considering whether Temasek should exit the business.

As part of a systematic review of earlier policies, the government has recently formed a high-level Economic Review Committee that brings together senior executives of global corporations, government planners, venture capitalists, and academics, to design effective strategies for value creation through innovation. The Sub-Committee on Manufacturing that is chaired by the Chairman and CEO of Philips Electronics Asia-Pacific, has identified the following objectives for Singapore's upgrading strategy in the electronics industry. First, to develop unique "system integration" capabilities in a few key sectors (primarily storage and semiconductors), where Singapore should "host the entire value chain of activities from R&D, applications development and 'test bedding', to (the) development of new markets." (Economic Review Committee, 2002a: p.24). Second, for innovation to blossom, it needs close interaction with manufacturing. It is suggested to deepen the division of labor between Singapore (for knowledge-intensive activities) and the close-by Riau islands of Bintan and Batam in Indonesia (for labor-intensive production)[27].

Third, it is suggested to build specialized and flexible ("plug-and-play") infrastructures for the country's key electronics clusters. In the semiconductor industry, for instance, the development of shared facilities would enable all participants (i.e. wafer fabs, assembly lines, vendors of materials and production equipment, etc) to reduce their individual cost burden of externalities. The ERC report specifically identifies shared utilities, chemicals, gases and waste treatment for gas and water. Fourth, equally important are concerted efforts to complement domestic innovative capabilities with international knowledge sourcing. By definition, Singapore's domestic innovative capabilities are bound to remain

[27] It is argued for instance that global contract manufacturers, like Flextronics, may want to use Singapore as a regional hub to carry out product design (ODM) and rapid prototyping of system products such as computers and storage devices. "At the same time, they can use the Riau islands as a low-cost yet nearby location for labour-intensive manufacturing, to be managed and/or supported out of Singapore. " (Economic Review Committee, 2002a: p.26). This requires massive investments to improve logistics for movements of goods; to improve movement of commuters (technical staff based in Singapore to support Riau operations); to develop local support industries in Riau; and provide welfare and goodwill that is necessary for sustaining political stability (Economic Review Committee, 2002b)

limited. Recruitment of expatriates with scarce specialized skills provides an important leverage for accelerating domestic learning. Bringing in foreign skills also helps to constrain the growth of wages[28].

International knowledge sourcing however also involves the public sector, and attempts to create new forms of collaboration between public research institutes and global corporate R&D organizations. Specifically, it is suggested that public research institutes "should try and cooperate with corporate R&D organizations overseas and leverage Intellectual Property assets to attract these companies to innovate in Singapore." (Economic Review Committee, 2002a: p.13).

c. Korea

In response to the traumatic impact of the 1997 financial crisis, Korea's mix of upgrading strategies suggest a radical break with the pre-crisis development model of its electronics industry. From a chaebol-dominated industry structure, characterized by octopus-like diversification into ever-new markets for mass-produced commodities (Ernst, 1994), a new system is proposed that is characterized by four building-blocks (interviews in Korea, September 2002):

- let thousands of "new technology-based firms" blossom;
- develop a broad set of capabilities for chip and system-on-chip design
- spearhead and test-bed new mobile Internet applications; and
- become a leading platform and contents developer.

To implement this ambitious strategy, the government has pushed through a set of high-priority policies that encompass, *inter alia*:

- a serious attempt to restructure the vertically integrated chaebol system;
- a massive effort, personally backed by the President[29], to establish leading-edge information infrastructures and network systems across the country, to transform various government services using information systems, and to encourage firms to adopt Internet-based information systems;
- multiple initiatives to support the development of electronic design capabilities, such as the establishment of an ASIC Design Support Center, an Integrated Circuit Design Education Center (IDEC), a System IC 2010 Project, and, backed by a $ 20 million government grant, an Inter-University System-on-Chip Campus (coordinated by Seoul National University), where related university institutes all over the country can join in curricula design and in the exchange of credits.

[28] The ERC report contains the following blunt statement: "During rapid upswings, the Government should consider raising the ceiling of foreigners allowed to work in the country to avoid wage inflation. " (Economic Review Committee, 2002a: pages 13, 14).

[29] The new Korean President Roh Moo-hyun shares this commitment with the former president Kim Dae-jun. The appointment of the former CEO of Samsung Electronics as the new minister of information and communications signals an aggressive policy to expand the country's infrastructure and capabilities.

Of particular importance are two developments that highlight the systemic nature of Korea's upgrading strategies. First, major building blocks of a sector-specific innovation system for electronic design (especially system-on-chip design) have been jointly developed by the government, public research institutions and private firms. This has strengthened the relationship between foundry firms, system firms and IP providers, creating a potentially significant market for test-bed applications in digital consumer electronics and communications. Second, Korean firms and public research labs have accumulated considerable capabilities to develop complex technology systems like TDX (a switching system) and CDMA-based communication systems. It is expected that these experiences in the development of large IT systems may provide the basis for developing a robust electronic design industry.

However, questions have recently been raised about the quality of results, and about necessary adjustments. For instance, changes in industry structure turned out differently than expected. While a few chaebol like Daewoo have been effectively dismantled, Korea's electronics industry continues to be dominated by a few oligopolists, i.e. Samsung Electronics, SK Telecom, Korea Telecom, and LG. Despite massive efforts through government-backed incubators and venture capital, to create a large pool of innovative start-up firms, only very few such firms have survived, primarily those that are linked to the "New Big Four". Equally important, the usage patterns of wireless Internet in Korea is skewed towards games, while communication (email), e-business applications, and research play only a marginal role (Yi, 2002: p.62). This raises doubts whether the Korean mobile Internet market can serve as a test-bed for major innovations. Only time will tell to what degree these "revisionist" views on Korea's upgrading prospects are influencing the strategies of Korean firms and government policies.

(d) Taiwan

In contrast to Korea, Taiwan was less affected by the 1997 financial crisis. Taiwanese electronics firms traditionally entered as "fast followers" during the growth stage of a particular product market - a strategy that was highly successful until recently. A key success factor was a capacity to combine low-cost production and quick response to changes in markets and technology (Ernst, 2000). Low-cost production was made possible by rigorous cost control management and the establishment of a low-cost supply base in China and Southeast Asia. Quick response relied on a flexible system of supplier networks characterized by temporary "spider web" arrangements that are assembled for the duration of a particular project, and then dissolved.

However, the downturn in the global electronics industry since late 2000 has exposed serious drawbacks of Taiwan's "fast follower" strategy: razor-thin profit margins are insufficient to support investment in R&D; high licensing costs constrain diversification into new product markets with higher profit margins; a limited accumulated portfolio of patents, despite rapid growth in U.S. patent filings; and an exposure to increasingly severe hollowing-out pressures, as more and more manufacturing and related support services are moving to lower-cost locations in China and Southeast Asia.

Taiwan has responded with a set of coordinated upgrading strategies (interviews in taiwan, November 2002): improvements are simultaneously pursued in product mix, process specialization, information management and product development and design. Three major inter-related objectives define Taiwan's approach to upgrading: First, to strengthen Taiwan's market position as an OEM and ODM supplier to global brand leaders against competition from global U.S.-based contract manufacturers. Second, to develop a broad set of capabilities in electronic design and especially system-on-chip (SOC) design. And, third, to create value through global brands, intellectual property rights (IPRs) and de facto industry standards.

The first objective requires a combination of parallel upgrading moves that encompass:

- diversification moves into new product markets, like mobile communication products (e.g., cellular phones, W-LAN) and digital consumer electronics (e.g., digital video and audio systems);
- significant improvements in process specialization and information management;
- an extension and deepening of regional production networks in China, moving from sourcing of parts and components towards verification of manufacturing processes, engineering support, as well as software development and basic research;
- improvements in process technology (e.g. nano-technology) to upgrade manufacturing operations in Taiwan; and
- enhanced capabilities in product development and design.

This brings us to the second objective. It is argued that, without strong capabilities in electronic and especially system-on-chip (SOC) design, it is impossible to achieve the first and the third upgrading objectives. Furthermore, in light of Taiwan's global leadership in foundry services, as well as in chip assembly & testing[30], there are now realistic possibilities to develop world-class Taiwanese competitors in fabless chip design. SOC design is perceived to be "the next battleground" for the global semiconductor industry (Lo, 2002). This reflects the increasingly demanding performance requirements of mass-market electronic systems (e.g., notebooks, hand-held PCs, PDAs, mobile phones, digital video systems): they all need to become lighter, thinner, shorter, smaller, multi-functional, power-saving, inexpensive, and faster. By integrating the whole system on a single piece of silicon, SOC design is expected to cope with these increasingly complex requirements. Specifically, SOC design is expected to shorten design cycle time, increasing the success rate of IC development, and to enhance the competitiveness and market share of the brand name companies that sell these systems.

[30] With the two world leaders, TSMC and UMC, Taiwan's foundry industry accounts for 73% of worldwide foundry revenues; its chip assembly and testing firms account for about one third of worldwide revenues.

To support the development of Taiwan's SOC design industry, the government has initiated a "National SOC Research Program", coordinated by the National Chiao Tung University in Hsinchu Science Park that consists of three components:

- *training & research*: the Ministry of Education is committed to recruit each year additional 85 specialized SOC teaching faculty over the next three years; and the National Science Council will fund SOC graduate research programs;
- *development of core SOC technologies* for wireless and optoelectronic systems, and for embedded processors; and
- *establishment of a Global SOC Design and Service Park* to attract leading global industry players, by providing them with quick and easy access to foundries, assembly & test services, design services, and a so-called "IP mall" that facilitates the exchange of design building blocks, the so-called IPR trade (intellectual property rights).

The third objective, i.e. the creation of global brands, IPRs and de facto industry standards, is the core of Taiwan's upgrading strategy. It critically depends on success with the second objective. And it is supposed to gain in importance over time, relative to the first objective. The underlying assumption is that leading Taiwanese electronics firms are now strong enough to pursue "technology leadership" strategies, at least in carefully chosen market segments. Timing is of critical importance: this strategy will only work if the company succeeds in setting de facto industry standards early in a new product's life cycle. This explains why quantitative increases in R&D/sales ratios and in U.S. patent filings alone are considered to be insufficient. Apart from the creation of more "basic" patents, the key to success are specialized management capabilities required for strategic marketing, global branding strategies and the negotiation of de facto standard alliances.

To implement these objectives, industrial policy has been organized as an interactive exercise, a "policy dialogue" among multiple participants (both national and foreign) in Tawain's electronics production and innovation networks. This policy dialogue originated from a variety of institutional arrangements that were designed to overcome through "collective action" the disadvantages of small size that initially characterized Taiwan's electronics firms (Ernst, 2000, APJM). These arrangements included R&D consortia, joint development of key components, and institutions for the provision of quasi- public goods (standardization, testing and certification, training, information sharing, knowledge exchange, joint marketing and brand recognition campaigns).

Taiwan's policy dialogue brings together a broad range of participants, including industrial planning agencies, state-owned development banks and investment funds, private venture capital, major Taiwanese electronics companies, affiliates of foreign firms, start-up companies, public research organizations, university research centers, foreign consultants, as well as the overseas Taiwanese science and engineering and business communities in the US, Japan, China and Europe. Over time, these individual and often *ad hoc* linkages and dialogues have been transformed into institutionalized mechanisms for consultation and coordination. This has enabled the Taiwanese government to engage the private sector in a national effort of identifying trajectories of technological diffusion and innovation, entry strategies and priorities for state action. The institutionalization of the industrial policy dialogue has also served as a locus of coordinating joint R&D activities and collaborative business strategies.

This policy dialogue operates on four levels (**Table 8: Taiwan's Industrial Policy Dialogue - Multi-Level Strategic Decision-Making**), moving from consensus-building on long-term vision down to the implementation and evaluation of specific projects. The key to this very important institutional innovation is that it allows for a high degree of resourcefulness and versatility in mobilizing multiple upgrading actors and their resources, as well as in soliciting policy contributions from outside the state apparatus and from outside Taiwan's borders.

The last aspect is of particular importance. There is a clear understanding that, as a small and politically isolated economy, Taiwan needs to rely on international linkages. The focus of these linkages however now moves from integration into global production networks to international knowledge sourcing. The following mechanisms of international knowledge sourcing are increasingly perceived as critical: close interaction with Taiwan's vast informal networks of overseas R&D engineers and managers in the electronics industry; participation in international R&D alliances and standard consortia; incentives for global corporations to establish R&D activities in Taiwan; the recruitment of top foreign engineers and researchers through attractive value-share bonus systems; collaborative R&D projects with leading global centers of excellence; and collaborative R&D projects with leading research labs and universities in China.

4.2. China's upgrading options as a "late-latecomer"

China's specific challenge results from the fact that it enters the electronics industry as a "late-latecomer". The scope for repeating earlier "easy" entry strategies is much more limited. For instance, offshore chip assembly, which, based on the availability of cheap labor, provided growth benefits to Taiwan, Singapore and Malaysia during the 1970s and 1980s, since then has become highly automated and requires a capital-intensive and sophisticated infrastructure. In addition, key sectors of the electronics industry are now dominated by a small group of global players from the US, Japan, Europe, as well as from Korea and Taiwan. In this sense, upgrading in China faces more demanding requirements.

Nevertheless, China's late-latecomer status also conveys competitive advantages that explain the country's new attractiveness for inward FDI. As described in section 2.3., China's upgrading strategies can build on a unique combination of five advantages that comprise a booming market for electronics products and services, the world's largest pool of low-cost specialized and easily re-trainable IT skills; a reasonably well developed domestic base of technological and innovative capabilities, and support policies pursued by the central government, as well as regional and local authorities to rely on GPNs as an accelerator of industrial upgrading. It is in this context that China can use as an initial "cash cow" strategy its vast cheap labor pool to muscle its entry into the low-end of the industry.

However, there is a broad consensus in China that simply creating cheap-labor manufacturing jobs is not a viable development strategy. If the country would passively rely on FDI, without complementary domestic support policies, it is unlikely that substantial upgrading would occur. A good proxy is the low labor productivity of foreign-invested enterprises in China (UNCTAD, 2003). Measured as the value added in US-dollars divided by the number of employees, labor productivity is lowest in China among the main Asian FDI destinations. It is $7,199 per employee in China, $ 22,940 in Malaysia, and $ 97,193 in Taiwan[31].

China's innovation policy is driven by three interrelated objectives (e.g., Einhorn, 2003; Naugthon and Seagal, 2001; Dahlman and Aubert, 2001). The first objective is to reduce the technology gap with Japan, Korea and Taiwan, to improve the country's appalling productivity record. A second objective is to use innovation to create new and better paying jobs through innovation, in order to reduce the potentially high social costs of massive industrial restructuring imposed by WTO membership[32]. A third objective is to strengthen the Chinese military by developing open software (Linux)-based command, control and communications software, as well as sophisticated avionics and naval electronics[33]. Finally, a fourth objective is to generate revenues through lower-price cloning of complex technology systems (like switching systems), and to generate rents by defining global standards.

Since the mid-1980s, China's government has initiated various programs to strengthen the country's innovative capabilities, and the electronics industry has been a priority target for such programs. It took some time however to develop appropriate institutional arrangements (e.g., Liu and White, 2002). Initially, these programs focused on public research institutions (the 863 program[34]) and state-owned enterprises (the 1988 Torch Plan), combined with selective partnering with a handful of preferred global corporations. The 1988 Torch Plan was meant to develop China's innovative capabilities in high-tech industries, primarily electronics, focusing especially on R&D and the commercialization of new technologies in state-owned enterprises. The Torch Plan also included the creation of so-called high-tech industrial parks all over the country. Successful examples are the high-tech parks established in Beijing (Zhongguancun, close to Beijing University and Qinghua University), Shanghai (ZhangJiang Hi-Tech Park), Suzhou (Suzhou Industrial Park), and Hangzhou (close to Zhejiang University).

Despite some achievements, the Torch Plan had major draw-backs (Naughton and Segal, 2002: pages 14 -15): many firms that entered the high-tech parks, primarily were

[31] Note that for domestic firms, China's comparative position is even worse. Labor productivity in China is $ 2,633 per employee in China, against $ 13,923 in Malaysia, and $ 20,533 in Taiwan.

[32] Recent estimates of these costs can be found in Takeuchi, 2003, and Sano, 2003.

[33] This objective has recently gained in prominence, in response to the new US preemptive military strike doctrine.

[34] The 863 program (so named, because it was established in March 1986) brings together researchers from the Chinese Academy of Sciences, other public research institutes and university labs on cross-disciplinary projects like computer-integrated manufacturing systems. Enterprises have not been involved in project selection or implementation.

interested in reaping the benefits of preferential tax incentives and export subsidies, without developing new technologies. Much of the program funding, furthermore went to state-owned enterprises, rather than to innovative private start-up companies. Finally, selective partnering with a handful of global corporations did not produce the expected improvement in domestic innovative capabilities.

This gave rise, since the early 1990s to a drastic revision of China's upgrading strategy in the electronics industry. An important element was the decision to open the floodgates for inward FDI from diverse sources, signaled by Deng Xiaoping's "Southern Tour" in 1992. Since then, a heavy reliance on FDI sets China's electronics industry apart from its counterparts in Japan, Korea and even Taiwan. This made it possible to exploit multiple competing foreign technology sources to enhance knowledge diffusion to Chinese firms, increasingly also to non-state technology enterprises. At the same time, aggressive domestic industrial and innovation policies enabled domestic electronics firms to grow and compete. The government encouraged domestic computer companies like Legend, a non-state spin-off from the Institute of Computing Technology of the Chinese Academy of Sciences (Lu Qiwen, 2000), or telecommunications equipment producers like Huawei, Datang or ZTE, to engage in international knowledge sourcing through joint ventures with foreign technology leaders and through participation in GPNs. The process of "opening-up" has culminated in China's WTO accession. Some observers feared that the resultant liberalization of trade and investment regimes would crowd out domestic firms, and that it would weaken China's capacity to support its electronics industry (e.g., Nolan, 2001, chapter 11). But thus far, there is little evidence of substantial constraining effects on upgrading strategies.

Five basic propositions inform China's emerging new upgrading strategy in the electronics industry. First, as a late-latecomer, China has to develop its own idiosyncratic approach to policies, support institutions and business strategies. The experiences of other countries, in Asia, but also in the US and Europe, can provide important insights. In the end, China has to come up with its own solutions, based on its own peculiar strengths and weaknesses. But, being a late-latecomer, also conveys important advantages. Low labor costs is one such advantage. But equally important is that China is less burdened with outdated digital information and communications systems than earlier latecomers like Japan, Korea and Taiwan. Of particular importance is the limited role played by "legacy" operating systems and standards. For instance, as China lags behind in its installed Internet infrastructure, it is free to push for a rapid transition of Internet hardware and software known as Internet Protocol Version 6 (IPV6). This distinguishes China from other countries, but especially from the US that would need to displace a lot of existing infrastructure and computer and network software. If China goes ahead and deploys IPV6 first, it could be the first country "to write the new software while the rest of the world plays catch-up." (senior AT&T software executive, quoted in Einhorn, 2003, p.80)

Second, given the rapid pace of change in the global electronics industry structure, upgrading the country's electronics industry involves multiple moving targets, hence solutions have to be constantly adjusted. Of critical importance is the choice of appropriate sequencing patterns for developing innovative capabilities. In some cases, this may necessitate a reversal of established sequencing patterns. As illustrated by the case of Legend, China's broad-based science and technology system makes it possible to start from service-centered product development and (re)-design, and then to move backwards via marketing to manufacturing. Equally important is a sufficient degree of flexibility in policies and institutions that allow for quick response and adjustments to abrupt changes in markets and technology, and to unexpected outcomes of upgrading policies.

Third, in light of its potentially insatiable market for electronic products and services, China has good chances to pursue a portfolio of concurrent upgrading strategies that combine selective knowledge sourcing with value creation through innovation. Take the development of China's chip design industry. Leading global specialized suppliers are well established now in Asia across all stages of the semiconductor value chain, from assembly and test, to wafer fabrication, design tools, and different stages of ED. For China, this opens up new opportunities to develop domestic design capabilities. For instance, the government has established two national multi-project wafer (MPW) service centers (one in Beijing, and one in Shanghai) that provide access to foundries and assembly companies, both from Taiwan (for sophisticated design rules) and from China. And seven government-supported Research Centers for Integrated Circuit Design (in Shanghai, Beijing, Suzhou, Wuxi, Hangzhou, Xi'an, and Chendu) provide a variety of knowledge-intensive services, including subsidized access to leading-edge EDA tools, that help to overcome constraints that individual Chinese design houses face when trying to transform their designs into silicon.

The real issue however is to gain design-ins with electronic system companies with products that face high-growth markets. China provides ample opportunities. There is a clear understanding that it would be unrealistic, at this stage, to try to compete in high-end IPs, like microprocessors. It is realistic however to develop design capabilities for IPs (especially for embedded processors) for the potentially huge domestic markets in consumer electronics and telecommunications equipment. The more design-ins can be gained in these sectors, the greater the chances of success for China's attempts to create alternative, so-called "non-standard" standards like EVD, TD-SCMA, Chinese language Linux-based operating systems and alternative designs to Cisco routers[35].

Fourth, there is a recognition in the relevant decision-making circles of existing weaknesses. There is also a fairly good understanding of the entry barriers and the risks involved in aggressive upgrading strategies. There is a huge gap in innovative capabilities. For instance, China's total R&D spending is about $ 11billion, compared to more than $233 billion for the US. In terms of their accumulated capabilities, even the best Chinese companies are way behind global Asian industry leaders like Sony, Samsung, Acer, Honhai, let alone Microsoft, IBM or Intel. The portfolio of commercially proven IPRs is still very limited, and China's position in software remains weak[36]. Other

[35] See earlier discussion in section 3.1.

[36] Chinese software exports in 2001 were a meager $ 720 million, mostly lower-end programming work for US global corporations. Note however that the government projects software exports to rise to $ 5 billion

widely discussed weaknesses include: the absence of efficient capital markets, especially for venture capital, which raises the barriers for new innovative start-up companies; the lack of global brand recognition, which is extremely costly and time-consuming to build; and a continuous brain drain, even during the current China boom[37].

There are intense debates about the appropriate pace of China's upgrading efforts. Those who argue for a cautious approach point to research on earlier experiences in Asia which has shown that it takes a long time to build a broad set of productive capabilities and related basic and intermediate innovative capabilities (e.g., Ariffin, 2002). Research and Taiwan and Korea shows that it takes even longer to move from there to high-end innovative capabilities and research capabilities (e.g., Kim, 1997; Ernst, 1994 and 2000, APJM). But proponents of a more aggressive strategy argue that the starting-point is different in China, as it has already a reasonably strong and broad-based set of innovative and research capabilities. The main issue in this view is how quickly and effectively these capabilities can be linked with and integrated into corporate innovation strategies pursued by SOEs and private electronics companies.

Fifth, and finally, there is a clear understanding that domestic efforts need to be complemented by multiple international linkages. Such linkages are considered to play an important catalytic role in facilitating and accelerating the upgrading of China's electronics industry. The focus however is moving away from an earlier heavy reliance on technological capabilities developed within affiliates of global flagships, and their eventual spill-overs into local firms. Also, earlier attempts (especially in the car industry) to trade market access in exchange for access to technology are widely considered to work no longer. There is a growing consensus that China needs to enhance international knowledge sourcing through linkages with foreign universities, research institutes, and consulting firms, and by tapping into the vast informal global peer group networks of overseas Chinese researchers, engineers and managers. These diverse international linkages can help Chinese electronics firms to bridge existing gaps in specialized skills and innovative capabilities; and they can facilitate changes in organization and procedures that are necessary to develop these capabilities locally.

4.3. Generic policy suggestions

Our analysis of Asian upgrading strategies in the electronics industry shows that creating pathways to innovation requires a very active involvement of the state (i.e. local, regional, and central government agencies, as well as a variety of intermediate institutions). But this involvement now takes on a very different form from earlier top-down "command economy" type industrial policies. It also differs from the "New Economy" liberalization doctrine.

Traditional Asian "developmental" policies are no longer feasible. With their top-down approach, controlled investment finance, and reliance on SOEs or chaebol, these policies

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by 2005. There are now well-funded programs to train software engineers, and to develop higher-level capabilities, especially in encryption and security programs.

[37] "America is sucking away all the best and the brightest in China" (Andy Xie, managing director of Morgan Stanley in Hong Kong, quoted in "High tech in China", Business Week, 28 October 2002)

are too rigid to cope with complex challenges and opportunities of the global network economy that have been explored in this paper. These policies also cannot cope with the conflicting needs of multiple and increasingly vocal domestic actors. In addition, traditional developmental policies are unable to cope with the high uncertainty and rapid changes in technology and markets that are typical for the electronics industry. Finally, in light of their protectionist focus, these policies are unlikely to generate and benefit from international knowledge linkages that, as we have seen, are of critical importance for pathways to innovation in the global network economy.

Neither can the "New Economy" liberalization doctrine cope with the new opportunities and challenges for Asian electronics industries that we have examined in this paper. This doctrine claims that, except for education, infrastructure and a few general incentives (for training and R&D), the state should get out of the way, and let transnational technical and venture capital communities make the necessary investments in innovative capabilities (e.g., Bresnahan, Gambardella and Saxenian, 2001). But there are two problems with this concept.

First, none of our countries has used this approach, and it is simply misleading to claim (as Bresnahan, Gambardella and Saxenian, 2001 do) that Taiwan has used such an approach. Taiwan's upgrading strategies in the electronics industry have gone through two different phases: from "late follower" to "fast follower"; and from "fast follower" to "technology leader". And throughout all these stages, the state did play an important role (Hsueh, Hsu and Perkins,2001; "Reengineering the Developmental State..", The China Review, March 1, 2002; Ernst, 2000, APJM). Our analysis of taiwan's upgrading strategies in the electronics industry confirms the renewed importance of the state.

A second even more serious problem with the "New Economy" doctrine is that it neglects the dramatic fall of that economy (Ernst, 2001, Economia e Politica Industriale). So deeply entrenched is that belief that it has survived the worst recession in the history of key sectors of the "New Economy" (especially telecommunications and computers). This is ironic in light of the fact that in the US, and especially on Wall Street and in Silicon Valley, the debate has moved on. The emerging consensus is that the concept of the "New Economy" is buried under a long list of unfulfilled promises. Alice Rivlin, a former vice chair of the U.S. Federal Reserve, and a co-author of a major study of the productivity effects of the Internet (Litan and Rivlin, 2001), argues that much of the "New Economy" propositions are "hopes and hunches" (quoted in the Financial Times, September 3, 2001, p.2). Even more ironic is that the US government certainly does not do what the proponents of the "New Economy" doctrine claim it does. Driven by national security concerns and by fears of loosing its technological leadership, the Federal government spends $ 2 billion a year on information technology research, coordinated through a variety of agencies including the Defense Advanced Research Projects Agency (DAPRA) which has played a prominent role in the development of the US computer and internet industry (Flamm, 1987; Naughton, 1999).

In light of the substantial challenges and barriers faced by Asian electronics exporting countries in their attempts to upgrade their electronics industries, there is no doubt that the state has to play an important role in these efforts. However, what worked in the past does not work any longer. Instead, new approaches to innovation policy are required that:

- strengthen the state's steering & coordination capacity;
- provide public goods/created assets (infrastructure; bottleneck skills; training & education);
- facilitate access to and diffusion of knowledge; balance this with the need to protect intellectual property rights (IPRs);
- encourage innovations in the financial sector;
- generate dialogues at various levels among multiple participants (local & foreign) in production and innovation networks;
- foster inter-active learning & innovation;
- provide social protection and retraining options for the losers of innovation;
- and facilitate international knowledge sourcing through corporate networks, institutional collaboration, and through diverse social networks (global peer group communities and expatriates).

Annex: Tables and Figures

Table 1. Electronics Production and Markets: Top Countries, 2002*, $M(% share of total)

	Production	**Markets**
USA	318,890 (25.6)	380,004 (30.3)
Japan	231,984 (18.6)	194.005 (15.5)
China	110,613 (8.9)	105,064 (8.4)
Korea	69,861 (5.6)	39,713 (3.2)
Germany	49,013 (3.9)	59,649 (4.5)
Taiwan	43,699 (3.5)	22.950 (1.8)
Singapore	39,916 (3.2)	21,889 (1.7)
Malaysia	39,216 (3.1)	14,525 (1.2)
Total	1,247,896	1,253,059

Source: own calculations, based on Yearbook of World Electronics Data 2002/2003, June 2002
*= figures are forecasts at 2000 constant values & exchange rates (inflation is not included)

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Table 2: Wafer Fabrication Moves to Asia

(quote latest figures from VLSI Research, in Semiconductor reporter)

Table 3. Taiwan's Top Electronics Products (2001): Ranking No.1

	Production Value		Production Volume		Export Value	
Item	US$M	World share %	units	World share %	US$M	World share %
1. Foundry	6,070	72.9				
2. Mask ROM	400	56.7	140 million	48		
3. IC Package	2,285	30.4	8774 million		1,097	14.6
4. Notebook PC	11,594	23.9	12,532 K	49	11,362	23.4
5. LCD Monitor	2,308	41.1	6,035 K	39.2	2,158	38.4
6. CD-R Disk			4,680 million	83.3%		
7. CD-RW Disk			167.2 million	70.3%		
8. DVD-Disk			257 million	74.5%		
9. PC Camera			8,700K	58%		
10. Ethernet LAN card	305.7		35,783 K	66		
11. HUB	228.6		41,868 K	74.8		
12. ADSL Modem	374		5,115 K	59.6		
13. Wireless LAN	482	29.5	5,710 K	60%	480.24	27.2
14. analog modem	436		38,823 K	41.7%		

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Table 4. Asian Trade Specialization Profiles: RCA and Leading Export Products

Country	Product	RCA '93	RCA '94	RCA '95	RCA '96	RCA '97	RCA '98	Share '93	Share '94	Share '95	Share '96	Share '97	Share '98
Korea	EDP	0.9	0.8	0.8	0.9	0.9	0.7	14.4	11.9	12.2	14.5	15.5	13.9
	Storage	0.2	0.3	0.4	0.7	1.3	1.1	0.5	0.8	1.0	1.8	4.1	4.1
	COMP	2.4	2.7	2.8	2.7	2.8	2.7	50.1	56.2	62.4	60.8	62.3	63.4
	SC	3.3	3.8	4.1	3.6	4.0	3.8	30.4	37.2	45.7	40.3	42.9	45.3
	Cons. Electronics	2.3	2.4	2.0	2.0	1.7	1.5	22.5	20.5	16.1	15.6	12.8	12.7
	Telecom	0.9	0.9	0.8	0.8	0.6	0.5	3.0	2.7	2.4	2.4	2.1	1.9
	Memo: Share of Electronics in Merchandise exports (%)	28.0	29.7	30.9	28.8	29.2	28.3						
Taiwan	EDP	2.5	2.7	3.0	3.4			39.4	39.0	41.6	45.0	44.62	45.29
	Storage	0.3	0.3	0.5	0.6			0.8	0.6	1.0	1.3	2.10	1.97
	COMP	1.9	2.0	2.1	2.2			37.2	39.3	41.6	40.2	41.93	40.86
	SC	1.6	1.8	2.0	2.2			13.7	16.8	20.4	19.6	22.05	21.77
	Cons. Electronics	1.4	1.5	1.2	1.1			12.9	12.0	8.5	6.8	6.42	5.98
	Telecom	1.7	1.7	1.6	1.6			4.9	4.8	4.1	4.0	3.59	4.20
	Memo: Share of Electronics in Merchandise exports (%)	29.5	31.0	34.3	35.8								
Singapore	EDP	4.6	5.1	5.1	5.4	5.5	5.2	40.7	38.6	39.4	42.8	44.1	44.6
	Storage	12.9	13.4	12.8	15.3	12.4	11.4	17.6	15.7	16.0	18.8	19.3	19.8
	COMP	2.7	3.4	3.4	3.6	3.7	3.7	29.4	35.4	38.5	38.0	38.9	40.7
	SC	3.2	4.0	4.2	4.5	4.8	5.0	15.7	19.4	23.8	23.9	25.0	27.4
	Cons. Electronics	3.1	3.2	2.9	2.9	2.3	1.7	15.9	13.7	11.6	10.4	8.7	6.8
	Telecom	1.1	1.2	1.1	0.8	0.7	0.6	1.9	1.9	1.6	1.3	1.1	1.1
	Memo: Share of Electronics in Merchandise exports (%)	53.0	58.8	60.7	60.7	60.6	61.4						
Malaysia	EDP	1.4	1.8	2.0	2.3	2.9	3.0	13.8	15.6	17.1	20.5	25.3	27.4
	Storage	0.0	0.1	0.8	0.2	3.7	4.1	0.0	0.2	1.1	0.3	6.3	7.6
	COMP	3.7	3.7	3.6	3.8	3.9	3.9	44.6	42.6	43.9	44.6	45.1	45.7
	SC	5.6	5.2	4.7	4.9	5.3	5.2	30.5	28.3	29.8	29.3	30.1	30.7
	Cons. Electronics	4.2	5.0	5.1	5.0	4.1	3.5	24.2	24.2	22.6	20.1	16.5	15.1
	Telecom	2.1	2.4	2.0	2.0	1.7	1.5	3.8	4.0	3.2	3.3	3.1	2.8
	Memo: Share of Electronics in Merchandise exports (%)	47.6	52.5	54.9	54.7	55.8	57.5						
Thailand	EDP	1.4	1.8	1.9	2.4	2.5		32.2	34.0	36.8	41.4	40.9	
	Storage	2.8	5.4	4.6	4.5	2.0		9.8	15.5	14.0	11.9	6.2	
	COMP	1.4	1.5	1.5	1.6	1.6		38.4	38.8	39.9	36.5	35.8	
	SC	1.7	1.6	1.4	1.6	1.7		20.8	19.3	19.5	18.8	18.3	
	Cons. Electronics	1.3	1.6	1.4	1.5	1.7		16.7	16.4	13.3	12.0	13.1	
	Telecom	1.2	1.1	1.0	1.2	1.2		5.2	3.9	3.7	4.1	3.9	
	Memo: Share of Electronics in Merchandise exports (%)	20.8	24.0	24.9	28.4	29.6							

Source: UN Trade Data Base Comtrade

Table 5. Vertical Specialization in the Electronics Industry

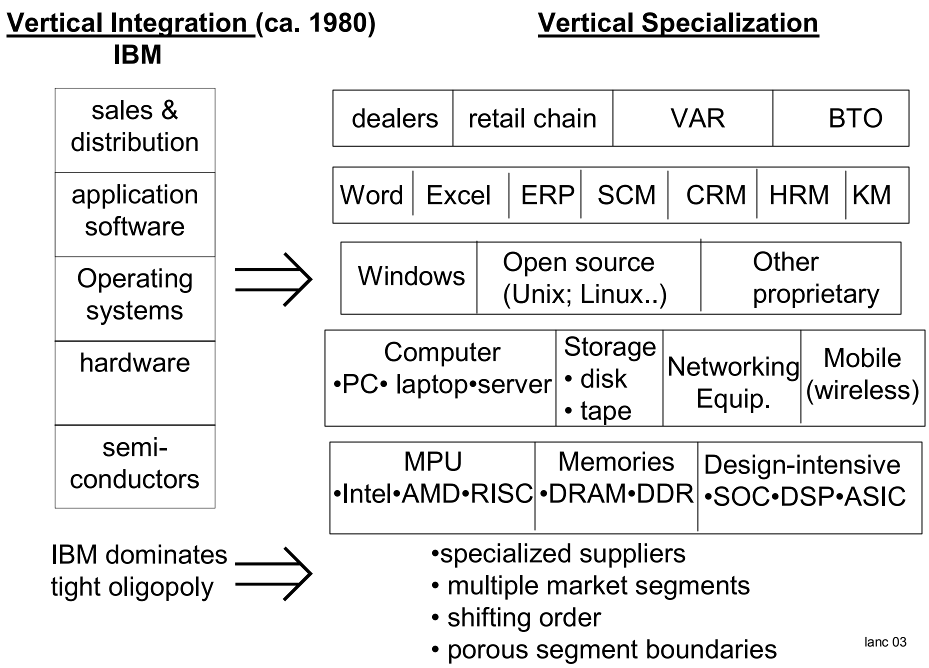


Table 6. Vertical Specialization: Semiconductor Industry

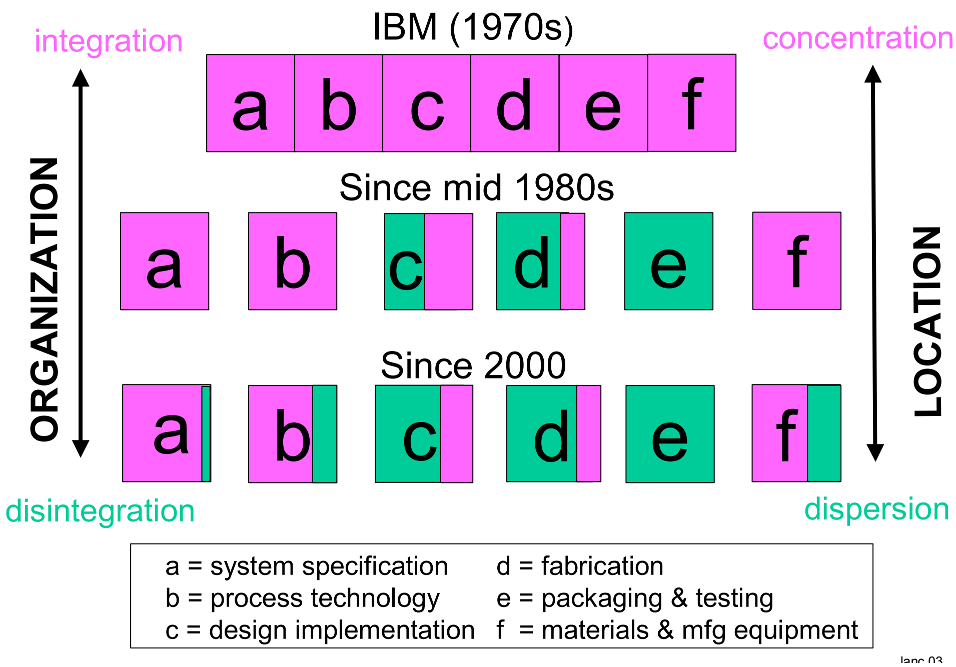
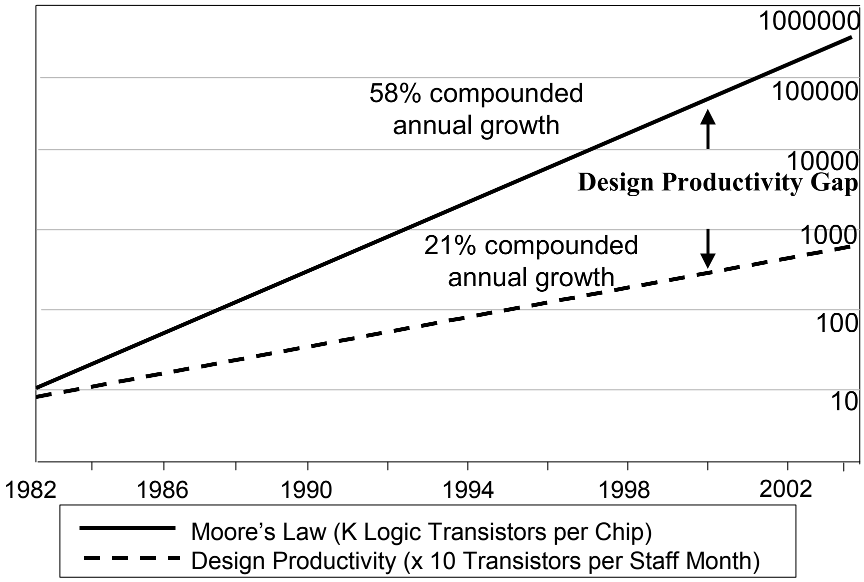


Fig. 1 Widening Design Productivity Gap in Integrated Circuits



(Source: SIA, 1999)

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Table 7. 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)

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Figure 2. THE NODES OF A GLOBAL PRODUCTION NETWORK

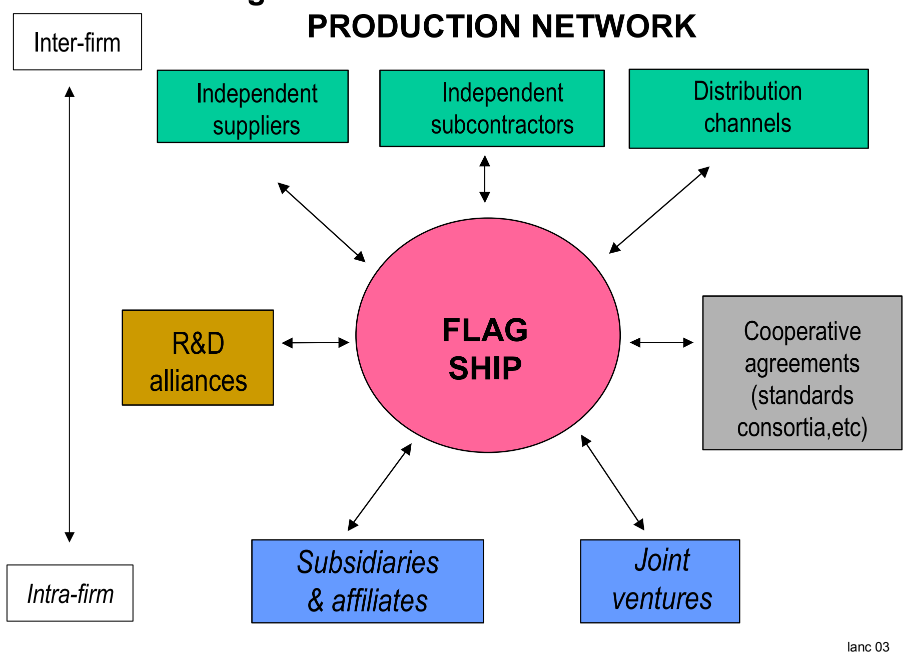
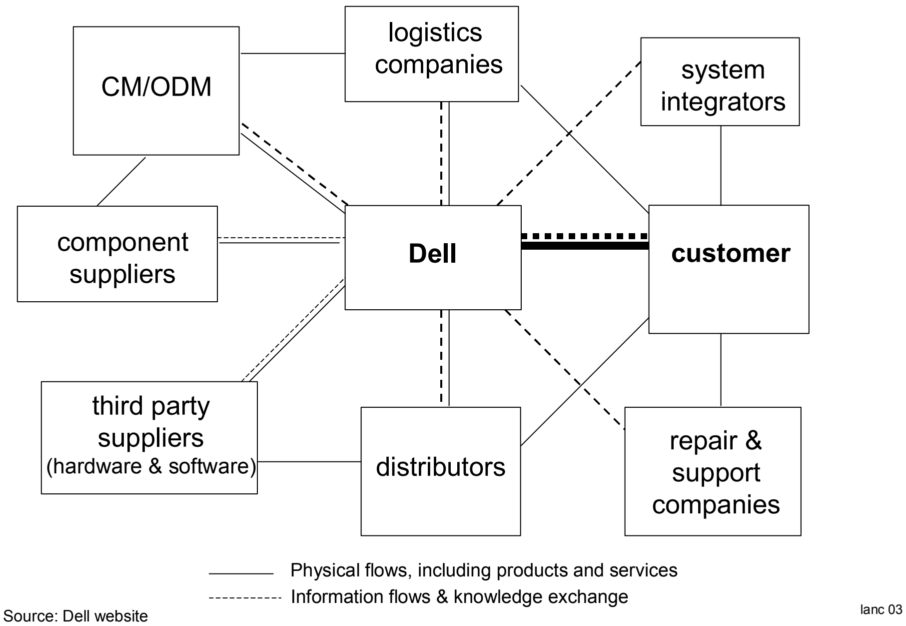


Figure 3. Dell's Global Production Network



Source: Dell website

Table 8. Taiwan's Industrial Policy Dialogue – Multi-Level Strategic Decision-Making

Levels	Tasks	Institutions
I. Consensus on Long-Term Vision	• technology road maps & markets • socio-economic implications • desirable industry profile • role of government	• annual STAG meetings • NSTC (every 5 years) • NII Steering Committee
II. Identifying Emerging Strategic Industries	• policy instruments • institutions • infrastructure • innovation systems	• Industrial Development Consultation Committees (MOEA) • bi-annual review of three industry lists: *emerging * upgrading *graduates
III. Medium-Term Development Plan for a Specific Industry	• entry barriers • SWOT • measures to be taken by specific government agencies & semi-public institutions	IDB, together with relevant Industrial Development Consultation Committees
IV. Implementation	evaluate product-specific or firm-specific projects	IDB commissions appropriate research units within GRI's to coordinate R&D consortia with domestic producers

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