Innovation offshoring and Asia's electronics industry – the new dynamics of global networks

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Abstract: This paper explores how innovation offshoring gives rise to Global Innovation Networks (GINs) in the electronics industry. The focus is on chip design. The paper documents the scope of offshoring and the progress achieved in the complexity of design stages and in capability upgrading in Asia. The paper explores the forces that are responsible for the organisational and geographical mobility of innovation within GINs emphasising their systemic nature. The paper argues that innovation offshoring is likely to accelerate Asia's transformation from the 'global factory' model to 'upgrading through innovation'. But massive challenges must be mastered before Asia's leading electronics exporting countries can exploit these opportunities. Such challenges result from the very demanding requirements that locations need to fulfil in order to qualify for R&D investments by Transnational Corporations (TNCs).

Keywords: innovation offshoring; GINs; global innovation networks; chip design; Asian electronics; TNCs; trans national corporations; global factory.

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1 Introduction

Asia's rise as the global factory in the electronics industry is an excellent example of the role Global Production Networks (GPNs) can play in shaping patterns of economic growth.[1] Early integration into these networks gave Asian manufacturers access to the world's largest markets, helping to compensate for the initially small size of their domestic markets.[2] Network participation also provided access to leading-edge technology and best-practice management techniques, creating new opportunities, pressures and incentives for Asian suppliers to upgrade their technological and management capabilities and the skill levels of workers.[3]

Aggressive support policies, implemented by Asian governments, enabled local firms to cope with these opportunities and to improve their position in these networks. The result is one of the most impressive success stories of Third World industrialisation. Asia's five leading electronics exporting countries (China, Republic of Korea, Taiwan Province of China, Singapore and Malaysia) account for roughly one-third of world electronics manufacturing output and occupy leading positions in high-growth, high value-added product markets. This process has culminated in China's emergence as the dominant global factory location. By 2004, China had become the largest exporter of Information and Communication Technology (ICT) goods (US$180 billion), surpassing the USA, Japan and the European Union, and the second largest importer (Table 1).

Table 1 Exports and imports of ICT goods, 1996–2004 (USA, China, EU15, Japan) (US$ billion, current prices)

Exports	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*
USA	124	141	135	148	182	152	133	137	149
China	19	23	27	33	47	55	79	123	180
EU-15	73	81	87	92	111	105	100	114	139
Japan	103	104	94	101	124	95	95	107	124
Imports									
Imports	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*
USA	150	163	169	193	238	194	194	200	235
EU-15	106	112	127	137	167	148	140	164	226
China[b]	17	20	26	35	51	57	76	111	149
Japan	48	46	41	49	67	58	55	61	73

Notes: Data for the EU exclude intra-EU trade.

Source: OECD, ITS database

[a]Top 10 exports of ICT items by China (4-digit HS code in US$ billion) in 2004 include process machines, magnetic reader computer hardware, parts, etc., for typewriters and other office machines, computer accessories, transmission apparatus for radio telephony/telegraphy/broadcasting, television, parts for television, radio and radar apparatus, integrated circuits, electric apparatus for line telephony or telegraphy telephone sets, teleprinters, modems, facsimile machines, Video recording or reproducing apparatus, television receivers, video monitors, video projection television receivers, parts and accessories of sound/video recording or reproducing equipment of;

[b]Top 10 imports of ICT items by China (4-digit HS code in US$ billion) in 2004 include integrated circuits, automatic data process machines, magnetic reader, etc. computer hardware, parts etc for typewriters and other office machines, computer accessories, parts for television, radio and radar apparatus, semiconductor devices, printed circuits, transmission apparatus for radio telephony/telegraphy/broadcasting, television, electrical capacitors, fixed, variable or adjustable: parts thereof, electric apparatus for line telephony or telegraphy telephone sets, teleprinters, modems, facsimile machines, parts and accessories of sound/video recording or reproducing equipment of.

While Asia's integration into GPNs has fostered export-led industrialisation, there are certain weaknesses that could constrain the region's longer-term industrial upgrading options. Despite an increase in intra-regional trade and investment, triangular trade has remained dominant, with the USA by far the most important final market for Asian exports, and Japan the main source of intermediate inputs and production equipment (Ernst and Guerrieri, 1998; Ng and Yeats, 2003). To remain within the GPNs, Asian countries had to provide well-educated factory workers, technicians and engineers at substantially lower cost than in the USA but the global factory model provided only limited opportunities for employing higher level knowledge workers. This resulted in a substantial brain drain, with the US electronics industry the main beneficiary.[4] Another defining characteristic of East Asia's global factory network model is that technology exchange has largely remained a one-way street. Typically, Asian firms had to rely on US, Japanese and European firms as the principal sources of new technology. This reflects the heavy concentration, much of it centred in the USA, of Research and Development (R&D), innovative capabilities and Intellectual Property Rights (IPRs) in industrialised countries.[5]

1.1 East Asia is becoming a location for innovation offshoring

Over the past few years, GPNs in East Asia have experienced fundamental changes that may help to redress these weaknesses (Ernst, 2002a; Ernst, 2002b; Ernst, 2004; Ernst, 2005d; Ernst, 2008a; Ernst, 2008b). Innovation offshoring has given rise to Global Innovation Networks (GINs), which Trans National Corporations (TNCs) are gradually grafting onto their existing production networks (Ernst, 2006). TNCs are extending vertical specialisation beyond manufacturing, pushing it deeper and deeper into the corporate innovation system. As a result, East Asia is emerging as an important location for innovation offshoring, in addition to its role as the primary global electronics factory.

TNCs offshore stages of innovation to East-Asian affiliates overseas through *intra-firm innovation networks* with the goal to tap into the lower-cost talent pool and innovative capabilities of East Asia's leading export economies (Figure 1).

TNCs also outsource some stages of innovation to specialised East-Asian suppliers through *inter-firm innovation networks* (Table 2).

Figure 1 Inter-firm networks – notebooks (see online version for colours)

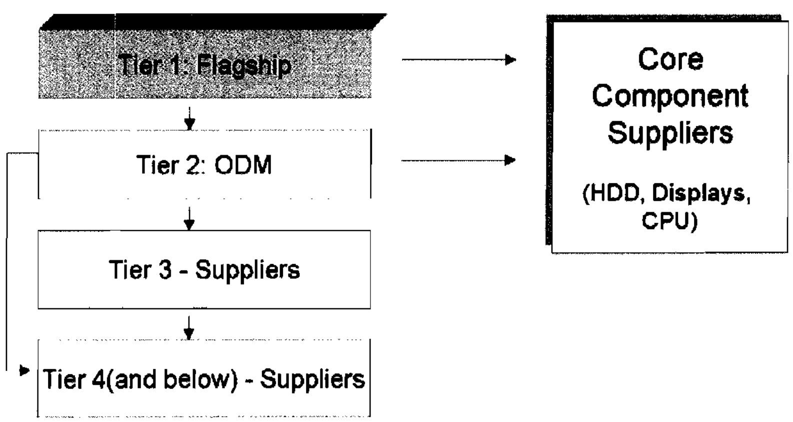


Table 2 Intel's GIN

Location	*Description*
USA (11 Labs)	Core technology development in Santa Clara, Folsom and Austin
Asia (7 labs, more planned)	• Bangalore (2700 = largest lab outside USA)
	• Leading-edge processor development
	• Penang (500), design implementation
	• Shanghai (100++) Linux based solutions for telecom; new applications for emerging markets
	• Beijing (50++), platform and architecture lab
Israel	• Haifa (1400, since 1974), processor research
Russia	• Nizhny Novogorod (200++), software

1.2 Governance in GIN

Both GINs and GPNs are complex, multi-layered 'networks of networks' that involve TNCs and local companies. GINs also share two defining characteristics with GPNs: (1) *asymmetry*: flagships dominate control of network resources and decision-making; and (2) *knowledge diffusion*: the sharing of knowledge is the glue that keeps these networks growing. As discussed later, the governance nature of flagship-dominated networks may actually facilitate knowledge exchange (Figure 1).

GINs reflect a shift in corporate strategy to open and integrate innovation model. The following three characteristics define this emerging new innovation strategy:

- innovation is fragmented ('modularised') and dispersed across boundaries (firms; geographic; sectors)
- firms complement in-house R&D with outsourcing and licensing
- innovation in operations and business models are as important as new products and services.

Over time vertical specialisation increased the number and variety of GIN participants, business models and design interfaces, bringing together teams from companies that differ significantly in size, market power, location and nationality, as shown by the GIN in handsets, established by a Chinese telecommunications service provider (Table 3).

Table 3 GIN – handsets

Functions	*Gin participants by location*
Telcom service provider defines system architecture	China
ODM suppliers of handsets	China
IDM provide design platform	USA
Intellectual property providers	UK and Taiwan Province of China
Fables design houses	USA, Taiwan Province, China and India
Foundries	Taiwan Province, Singapore and China
Chip packaging	Taiwan Province, China
Tool vendors for design automation and testing	USA and India
Design support service providers	Various Asian countries

1.3 How important is East Asia?

Much of econometric analysis focuses on a too narrow set of data and misses the hidden underbelly of innovation offshoring. Empirical work observes an increasing diversity of actors, locations, business models and network arrangements. US firms are leading and shaping the architecture of GINs. Asian firms also construct their own, mostly intra-firm, networks. In this paper, the term innovation offshoring is used to cover both processes. But innovation still remains geographically concentrated, because tacit knowledge is exchanged through social networks embedded in local institutions (universities, R&D, patents, start-ups, venture capitalist, legal and other knowledge-intensive support services). For the time being, established centres in the USA, Europe and Japan retain their dominance. All 15 leading companies with the best record on patent citations are based in the USA (9 in the IT industry). The 700 largest R&D spenders (mostly large US firms) account for 50% of the world's total R&D expenditures and more than two-thirds of the world's business R&D. More than 80% of the 700 largest R&D spenders come from only five countries (USA, followed by Japan, Germany, UK and France). However, Asia's role in these networks is rising, driven by the resurgence of China and India. Asia's share in high-tech manufacturing has drastically increased (Table 4).

Table 4 World's share of high-tech manufacturing by region and by country, 1985–2005 (%)

	1985	*2005*
Asia-10	29	41
Japan	25	16
China	2	16
USA	33 (1995: 27)	34

Source: National Science Board (2008), *Science and Engineering Indicators*, 2008

According to a recent survey of the world's largest R&D spenders (UNCTAD, 2005),[6] China is the third most important offshore R&D location (after the USA and UK), followed by India (6th) and Singapore (9th). China is the most attractive location for future foreign R&D, ahead of the USA and India. Leading global corporations also tend to expand their offshore outsourcing of R&D to Asian firms. EIU 2006 Survey shows that India and China are the second and the third most important offshore R&D location (after the USA and ahead of the UK). Leading global corporations consider India, the USA and China to be the best overseas locations for the future R&D. Two important pull factors explain the surge of China as a global R&D location: its rapidly growing market (Table 5) and a massive increase in China's R&D investments (Table 6).

Table 5 China's growing market

Telecom equipment (wired and wireless; test bed for 3 G)	Largest market
Semiconductors	Largest market
Handsets	Launch market
Cars	Second largest market
Digital communication equipment	Lead market (#2)
Less over-engineered products and services with substantially lower costs and acquisition and operation	'Bottom-of-the-pyramid' market
USA, Japan, Taiwan and Republic of Korea	Leading export market

Table 6 The rapid growth of China's R&D

R&D (CAGR, 1999, 2006, %)	>20
R&D /GDP (%)	0.7 (1999)
	(2006)
	2.0 (2010)
December 2006	China has become the world's second largest R&D investor (after USA, but ahead of Japan)

Source: PRC State Council data quoted in OECD, 2007

As East Asia is integrated into emerging GINs, important questions are raised for the study of industrial upgrading in developing countries:

- How will this affect the region's trade patterns, its access to the evolving global talent pool and its innovative capabilities?
- Will reliance on triangular trade centred on the USA and Japan give way to an Asianisation of trade and investment, centred on China?
- Can East-Asian countries replicate the US model of attracting top talent from the global market for knowledge workers to reduce emerging bottlenecks in the supply of well-educated and experienced technicians, engineers, managers and scientists?
- Can East-Asian firms enter the global innovation race (Baumol, 2002) as sources of new technology and global standards?

To answer these questions, it is necessary to know precisely what is happening. Yet, while the policy relevance of these developments is all too evident, little research exists that addresses the root causes and impacts of innovation offshoring. This paper presents some preliminary observations on possible causes and outlines main policy implications. The analysis in this paper focuses on the electronics industry, which dominates East Asia's trade and foreign direct investment and uses chip design as a test case to examine what forces are driving the offshoring of innovation. Section 2 introduces a conceptual framework to analyse the growing organisational and geographical mobility of innovation within GINs that makes innovation offshoring possible. Section 3 summarises the findings of the case study, indicating the scope of offshoring and the progress achieved in the complexity of design and in capability upgrading in Asia. Section 4 highlights the systemic nature of the forces that are driving the offshoring of chip design. Section 5 concludes with outlining challenges Asia is confronting in pursuing the transformation from global factory to an important location of innovation offshoring.

2 Root causes of 'innovation offshoring'

2.1 Growing organisational and geographical mobility

The idea of innovation offshoring runs counter to established wisdom in innovation theory. Barney (1991), for instance argues that, for a firm to grow, it must control resources that are valuable and rare, and in the absence of technology markets, firms must invest in creating 'co-specialised assets' (such as the production of core components and accumulated knowledge of customer requirements) to maximise their returns from innovation. And Edith Penrose, in her pioneering study '*The Theory of the Growth of the Firm*', concludes that "...a firm's rate of growth is limited by the growth of knowledge within it", emphasising the capacity for knowledge integration.[7]

A second argument, against the idea of innovation offshoring, is the proposition that physical proximity is advantageous for innovative activities that involve highly complex technological knowledge. Patel and Pavitt (1991) use patent data to demonstrate that the innovative activities of the world's largest firms are among the least internationalised of their functions. They argue that firms tend to concentrate innovation in their home country, in order to facilitate the exchange of complex knowledge. Hence, complexity explains why innovation remains an important case of non-globalisation.

However, research on globalisation has clearly established that economic institutions now extend well beyond the national economy (Dunning, 1998). International linkages proliferate, as markets for capital, goods, services, knowledge and labour are integrated across borders (Ernst, 2005c). While integration is far from perfect in markets for technology, it is nevertheless transforming the geography of innovation (Ernst, 2002a). The result has been a gradual opening and networking of corporate innovation systems that are well documented (Vonortas, 1997; Arora et al., 2001; Coombs and Georghiou, 2002; Brusoni, 2003; Chesbrough, 2003). For instance, the *Science and Engineering Indicators 2004* report by the US National Science Board highlights the increasing importance of innovation networks that cut across sectors and national borders. The report argues that

> "the speed, complexity, and multidisciplinary nature of scientific research, coupled with the increased relevance of science and the demands of a globally competitive environment, have encouraged an innovation system increasingly characterized by networking and feedback among R&D performers, technology users, and their suppliers and across industries and national boundaries"
>
> (National Science Board, 2004, vol. 1, pp.4–36)

This growing organisational and geographical mobility of innovation is captured in Cantwell's important observation that, instead of a few pre-eminent centres of innovation, there are now "multiple locations for innovation, and even lower-order or less developed centres can still be sources of innovation" (Cantwell, 1995).[8]

2.2 Global markets for technology and knowledge workers

Arora et al. (2001) demonstrate that the increasing division of labour in innovation drives the gradual opening of corporate innovation systems.[9] This gives rise to the development of global markets for technology, creating more space for the gradual opening and networking of corporate innovation systems. Firms can now outsource the creation of knowledge that is needed to complement their internally generated knowledge.

Markets for technology actually increase the penalty for the 'not invented here' syndrome, i.e. a reluctance to use external technologies. As the mobility of knowledge increases, a firm's competitive success critically depends on its ability to monitor and quickly seize external sources of knowledge (Iansiti, 1997). As demonstrated by Iansiti and West (1997), a company can leverage basic or generic technologies developed elsewhere, which allows it to focus on developing unique applications that better suit the needs of specific overseas markets. Industry leaders can now attempt to balance in-house innovation and external knowledge sourcing. But, as demonstrated in the case study below, external knowledge sourcing can also provide a shortcut for late entrants from developing countries. For instance, companies that trail behind industry leaders in their in-house technological capabilities can now use external technology sourcing to enhance their in-house innovative capabilities (Ernst, 1997; Ernst, 2000).

Markets for technology also create new opportunities for appropriating innovation rents through technology licensing. The underlying assumption is that, once markets for technology exist, knowledge will be sufficiently codified and IPRs will be well defined and protected (Kogut and Zander, 1993). Technology licensing supplements innovation offshoring, as it provides the necessary financial means. But innovation theory also shows that an excessive reliance on technology licensing may be risky, as it may cut off the company from vital system integration knowledge that is necessary for continuous innovation (Grindley and Teece, 1997).

2.3 Increasing availability and mobility of knowledge workers

Equally important for the gradual opening of corporate innovation systems has been the growing availability of knowledge workers outside the dominant corporations and their rapidly increasing geographical mobility, first within the USA (the GI bill after World War II), then in Europe (Marshall Aid for reconstruction and later various rounds of EU enlargement) and Japan, and, after 1970, in the Newly Industrialising Economies of East Asia. In all of these regions, as well as in China, India, Brazil and Russia, government policies to improve education and training, and to enhance their interaction with business needs, have helped to increase the supply of knowledge workers.

The result is an evolving global market for knowledge workers (Farrell et al., 2005). According to the US National Science Board (2004, Vol. 1, Chapter 1, p.8), more and more governments are implementing aggressive policies designed to attract highly trained and experienced engineers, scientists and R&D managers from abroad. At the forefront are advanced developing countries (primarily in Asia) that 'are expanding their higher education systems and the high-technology sectors of their economies in an effort to develop internationally competitive centres of excellence. In the past, these (advanced developing) countries have been the main source of internationally mobile scientific and technical talent, but recently some of them have developed programs designed to retain their highly trained personnel and to even attract people from abroad'.

TNCs are responding to the growing competition for scarce global talent, "by opening high-technology operations in foreign locations, developing strategic international alliances, and consummating cross-national spinoffs and mergers" (National Science Board, Vol. 1, pp.0–3). For some bottleneck skills, such as experienced design engineers for analog integrated circuits, this may lead to global auction markets for knowledge workers, enabling them to sell their talents to the highest bidder. This has enabled US start-up companies to pursue 'learning by hiring away' strategies – they can rapidly ramp up complex innovation projects with highly experienced personnel trained by other corporations or countries. Overall, however, the emergence of a global market for knowledge workers seems to have kept a tight cap on increases in remuneration. The main beneficiaries are major TNCs – by shifting from national to global recruitment strategies, they are able to reduce the cost of research, product development and engineering.

2.4 Conceptual building blocks

In response to these developments, research on the internationalisation of innovation has received a boost, but it is still at an early stage. Few robust data exist on the drivers and especially the impacts of these processes. Efforts to close this gap have focused primarily on the internationalisation of innovation among industrialised countries. However, there is little research on what is driving the more recent offshoring of innovation to new lower-cost locations outside the established centres of excellence in the USA, Japan and Europe. And even less is known about possible impacts and effective policy responses.

Nevertheless, recent research on the internationalisation of R&D does provide theoretical and empirical building blocks for the analysis of innovation offshoring. That literature typically explores under what conditions the centrifugal forces for geographical concentration are stronger than the centripetal forces for geographical dispersion (Granstrand et al., 1993; Cantwell and Iammarino, 2003). A basic preposition of this literature is that the objectives of innovation management and the resultant motives for internationalising R&D determine what types of R&D are performed at overseas locations.

Forces driving geographical concentration include:

- proximity to the familiar home country market creates firm-specific technological advantages (Linder, 1961)
- highly complex innovative activities favour proximity (Pavitt, 1999)
- the fear that unwanted technology leakage may increase with geographical dispersion of R&D
- economies of scale are difficult to replicate in geographically dispersed R&D labs
- the substantial transaction cost of coordinating international R&D labs
- path dependency or the sheer force of a company's historical roots in a particular location

There is a growing recognition that the globalisation of markets, technology, competition and strategy, and the resultant opening of corporate innovation systems have boosted the forces for geographical dispersion of R&D. Much of the literature typically examines pull factors that attract R&D to particular locations. These include demand-oriented and supply-oriented forces and policies. A key proposition is that centrifugal forces can be stronger than centripetal forces, when the host country market is large, grows rapidly and gains in sophistication.

A second proposition highlights the growing importance of supply-oriented forces, especially in high-tech industries like electronics (Ernst, 1997; Dalton and Serapio, 1999, p.40). Proximity to global manufacturing bases matters, but increasingly important is the search for lower-cost overseas R&D personnel and for new ideas and innovative capabilities. Granstrand et al. (1993, p.417) highlight the critical role of external knowledge sourcing. As the pace and cost of technological development rapidly escalate, and as the sources of breakthrough general-purpose technologies proliferate, TNCs are forced to seek 'access to a wider range of scientific and technological skills and knowledge than is available in the home market'.

A third proposition highlights the role played by policy factors, such as tax rebates and other financial incentives, regulations, policies on IPRs, as well as the provision of infrastructure, education and other public good services. Through their impact on the relative cost of conducting innovation across locations, policy factors can act as additional powerful drivers for the internationalisation of innovation (Callan et al., 1997). In fact, more and more TNCs seek to reap the benefits of policies and incentives that are provided by governments to attract foreign R&D investments as a catalyst for developing local talent pools and innovative capabilities.

This has given rise to a burgeoning literature on taxonomies of overseas R&D.[10] Most widely used are taxonomies that, drawing on Kuemmerle (1996), distinguish between 'home-base-exploiting' and 'home-base-augmenting' overseas R&D labs. Home-base-exploiting overseas R&D has been around for a long time – its *raison d'être* is to transfer knowledge from the home base for commercialisation in overseas markets. The key requirement for overseas R&D is the adaptation of products, services and production processes to local needs and resource endowments. By contrast, home-base-augmenting overseas R&D grew in importance during the last decades of the 20th century. Its rationale is external knowledge sourcing – to tap into new knowledge from an increasing number of overseas local innovation clusters; to transfer that knowledge back to the TNC's home base (Kuemmerle, 1997, p.66); and to combine these diverse technologies to create new products and processes (Granstrand et al., 1997). Hence, augmenting overseas R&D requires much more than adaptive engineering, and includes product development as well as applied and fundamental research.

2.5 Changes in corporate innovation management

The simplicity of this taxonomy explains its success in shaping debates on R&D internationalisation. Yet fundamental changes have occurred in the parameters of corporate innovation management since the 1990s, and a fresh look needs to be taken at the link between mtives for internationalising innovation and the types of R&D performed overseas. To capture these changes, the analysis needs to include push factors, i.e. changes in the methodology and organisation of innovation. The challenge is to explore how these changes have forced TNCs to outsource stages of innovation to specialised suppliers (*dis-integration of innovation value chains*) and to offshore them to new lower-cost locations (*geographic dispersion*). The analysis also needs to address the role played by two types of enabling factors as facilitators of knowledge diffusion, i.e. ICT-enhanced information management and transnational knowledge communities.

An important driver of these changes is a much more aggressive focus on reducing costs at all stages of innovation. And the fast pace of innovation and its disruptive nature (Christensen, 1997) have provoked fundamental changes in innovation management, giving rise to more open and networked corporate innovation systems.[11] No firm, not even a global market leader like IBM, can mobilise *internally* all the diverse resources, capabilities and bodies of knowledge that are necessary to cope with the above challenges. This has forced TNCs to rely much more on external knowledge sourcing, through GINs that extend beyond corporate and geographical boundaries. TNCs must supplement the in-house creation of new knowledge and capabilities with external knowledge sourcing strategies. There are strong pressures to reduce in-house basic and applied research and to focus primarily on product development and the absorption of external knowledge (Chesbrough, 2003). No longer does this externalisation of innovation stop at the national border – thanks to the evolving global markets for technology and knowledge workers, TNCs now can tap sources of knowledge that are located overseas (Ernst, 2002a; Ernst, 2003). As a result, TNCs have extended vertical specialisation beyond manufacturing and have pushed it deeper and deeper into the innovation value chain.

TNCs can draw substantial strategic benefits from the opening and networking of corporate innovation systems. Corporate innovation management needs to address four tasks simultaneously: develop innovative capabilities (including R&D);[12] recruit and retain educated and experienced knowledge workers; develop and adjust innovation process management (methodologies, organisation and routines) in order to improve efficiency and time-to-market; and match all three tasks with the corporation's business model, which determines customers, market segments, pricing, and the degree of insourcing and outsourcing, and hence defines the structure of required distribution, production and innovation networks. All four tasks are intrinsically interdependent. But of greatest importance is compliance with the firm's business model. In fact, if a firm pursues the first three tasks without a clear definition of the business model, this is likely to produce commercial failure.

2.6 The importance of innovation offshoring

Innovation offshoring may facilitate the matching of business model and technology roadmap. It can also help to identify and address blind spots that have gone undetected within a closed innovation system.[13] This is of critical importance, as the increasing complexity of technology roadmaps poses a serious challenge to corporate innovation management. Take the *International Roadmap for Semiconductors (ITRS)*, co-published by the semiconductor industry associations of the USA and other leading semiconductor exporting countries (ITRS, 2004). Until the mid-1990s, its primary concern was to coordinate requirements *within* fabrication that needed to be fulfilled to extend Moore's Law.[14] The roadmap thus focused on defining interfaces between a variety of complementary semiconductor manufacturing technologies, including photolithography (the process of using light to etch a circuit pattern on a chip), the mask (the device that contains the circuit pattern), the chemical agents used to impart the pattern, the physical size of the wafers used to hold the etched pattern, and the equipment used to measure these tiny distances reliably and accurately (SIA, 1999). For each of these different innovation agents, the roadmap defined the sequencing of complementary innovations, so that these technologies are produced at the moment when other required technologies will also be available, instead of being delivered too early or too late.

Today, the semiconductor roadmap is substantially more complex, and needs to coordinate multiple interfaces between the design, fabrication and application of semiconductor devices that increasingly integrate systems on a chip (Ernst, 2005a; Ernst, 2005b). Hence it is much more difficult to match technology roadmap and business plans. As the case study below demonstrates, this has given rise to a progressive vertical specialisation of innovation within Global Design Networks (GDNs).

2.7 Implications for overseas R&D by TNCs

The above changes in corporate innovation management are reflected in the changing perceptions of TNCs of their overseas R&D centres in developing countries. The findings of a study on R&D investment by major TNCs in China, conducted for the Industrial Research Institute (Armbrecht, 2003), highlights the following advantages of sitting industrial R&D in China:[15]

- the supply of talented manpower exceeds demand – at least for foreign firms; universities and research institutes are eager to get funding from private firms
- agreements on IPRs are possible with the top Chinese universities
- there are a large number of high-tech parks with excellent infrastructure
- locations compete with lavish incentives
- a 'techno-philic' bureaucracy facilitates negotiations
- substantial cost reductions are possible across all stages of the R&D value chain

The IRI study emphasises that, while cost savings matter, TNCs should expand their R&D in China primarily for strategic reasons, i.e. to tap into the vast pool of talent and ideas and to stay abreast of competitors in the increasingly sophisticated markets of China and Asia. It predicts a substantial increase in TNC R&D in China, and argues that the focus of these R&D labs is shifting from support and adaptation to the sourcing of China's emerging technologies and talent pools. The taxonomy in Table 7 attempts to capture this evolution of TNC R&D in China.

Table 7 Taxonomy of TNC R&D labs in China

Type	*Characteristics*
Satellite	• Listening post to detect ideas, incentives and innovations that reflect local market characteristics
	• Adapt existing products and processes
	• Vulnerable to budget cuts
Contract R&D	• Exploits lower-cost skills, capabilities and infrastructure
	• Implements discrete module of a global research project
	• Close interaction with R&D teams at headquarters and other affiliates
	• Tight mechanisms to control IPR leakage
	• Dense information flows, but unequal knowledge exchange
More equal partnership	• Full integration into TNC R&D strategy
	• Centre has regional or global product mandate
	• No barriers to full-fledged knowledge exchange

Sources: Walsh, 2003 and author's interviews

Satellite R&D labs, the least developed type of lab, combine elements of 'home-base-exploiting' and 'home-base-augmenting' R&D. What really distinguishes these labs is their relatively low strategic importance, reflected in their vulnerability to budget cuts decided by the TNC headquarters. Contract R&D labs describe the pure-play version of innovation outsourcing. For these labs, China's role is confined to the provision of lower-cost skills, capabilities and infrastructure. While dense information flows link these labs with R&D teams at headquarters and other affiliates, knowledge exchange remains tightly controlled and highly unequal. The highest stage, (more) equal partnership labs, is reserved for those R&D labs of TNCs that are charged with a regional or global product mandate. For these labs, barriers to knowledge exchange are supposed to be much lower, and are eventually expected to give way to fully fledged mutual knowledge exchange.

Research documents that satellite and contract R&D labs continue to dominate (Li and Jing, 2003; Gassmann and Zheng, 2004; von Zedtwitz, 2004). There are, however, also examples of (more) equal partnership arrangements, especially related to the development of China's alternative standards in mobile telecommunications, open source software and digital consumer electronics (Ernst and Naughton, 2005).

3 Case study on chip design – main findings

The recent expansion of chip design in (non-Japan) Asia provides an interesting test case for the study of innovation offshoring. From practically nothing during the mid-1990s, Asia's share of worldwide chip design projects shot up to around 30% in 2002 (iSuppli, 2003, p.21) although this is still far smaller than North America's share of 60%. But Asia is the fastest expanding market for Electronic Design Automation (EDA) tools, growing by 36% in the first quarter of 2004, compared with growth of 5% in North America, 4% in Europe and a fall of 2% in Japan (EDA Consortium, 2004). Taiwan Province of China has emerged as a primary new location for chip design, with the Republic of Korea following closely behind. Chip design is growing rapidly in China and India, as well as in Singapore and Malaysia.

To move beyond such broad-brush figures, a study (Ernst, 2005a) conducted exploratory, semi-structured interviews during 2002 and 2003 with a sample of 60 companies and 15 research institutions in the USA, Taiwan Province of China, Republic of Korea, China and Malaysia that are involved in electronic design (for integrated circuits as well as systems). The sample contains some of the main global and regional carriers of chip design in Asia. It includes specialised *research institutes* as well as nine *strategic groups of firms*[16] that participate in GDNs. Figure 1 illustrates what a GDN looks like: system companies; Integrated Device Manufacturers (IDMs); providers of Electronic Manufacturing Services (EMSs) and Own Design and Manufacture Services (ODMs); fabless chip design houses; chipless licensors of Silicon Intellectual Properties (SIPs); chip contract manufacturers (foundries); vendors of EDA tools; chip packaging and testing companies; and design implementation service providers.[17]

Over the past few years, all the interviewed TNCs have made substantial investments in chip design-related activities in Asia, and they are planning to expand them. These investments are likely to be concentrated in a handful of emerging Asian electronic design clusters in Taiwan Province of China (Hsinchu and metropolitan Taipei), Republic of Korea (primarily Seoul), China (primarily Beijing, Shanghai, Hangzhou, Suzhou and Shenzhen), India (primarily Bangalore, Hyderabad and Noida/New Delhi), Singapore and Malaysia.[18]

3.1 Design implementation vs. system specification

It is important to emphasise that substantial progress can be seen in the complexity of Asian chip design projects. The interviews show that design implementation continues to play a dominant role, but that system specification is gaining in importance.[19] Design implementation remains the defining characteristic for providers of ODMs and (more recently) for providers of EMSs. This reflects a long experience in board-level design that goes back to the early 1980s (Ernst and O'Connor, 1992), but today it covers very complex multi-layer boards. Combined with the experience in detailed product design and engineering that Asian firms have accumulated in the fabrication of integrated circuits, board-level design has given rise to a broad portfolio of design implementation capabilities. Design implementation also remains an important strategic focus of Taiwanese design houses. In line with earlier research by Chang and Tsai (2002), the interviews highlight the competitive strengths of these firms in the speed, cost, flexibility and quality of providing design implementation services.

Interview responses also show considerable progress in system specification. There are strong incentives – a capacity to specify systems and applications provides leverage for defining global standards and for innovation rents via premium pricing. One approach, chosen primarily by Taiwanese design houses, are niche strategies as suppliers of SIPs. However, the main Asian carriers of system specification are leading system companies (especially from China, Republic of Korea and Taiwan Province of China) that are producing innovations in the design of complex system architectures, primarily for wireless telecommunication systems.[20] Finally, global system companies and IDMs report that their rapidly expanding design centres in Asia perform both design implementation and system specification, mainly for Asian markets.

Design complexity has also improved, in terms of the line-width of process technology (measured in nanometers); the use of analog and mixed-signal design (that are substantially more complex than digital design); the share and type of system-level design (e.g. System-on-Chip (SoC), system-in package, structured Application-Specific Integrated Circuits (ASICs)); and the number of gates used in these designs. The interviews show that a few leading Asian firms from the Republic of Korea and Taiwan Province of China, and also from China and India, are conducting design projects at the frontier of technology.

The primary carriers of complex design projects are system companies, IDMs, foundry service providers and a few design houses. By nationality, design complexity is highest for Korean and Taiwanese firms as well as Chinese telecommunications equipment vendors. The rest of the Asian sample firms are positioning themselves at least one generation behind the leading-edge in design complexity as fast, but cheaper, followers, which is a considerable achievement relative to the situation only a few years earlier. Finally, the Asian design centres of TNCs (meaning firms based in the USA, Republic of Korea and Taiwan Province of China) report a wide range of design complexity levels, reflecting the diverse functions of these centres.[21]

4 Drivers of chip design offshoring

This section highlights the systemic nature of the forces driving the offshoring of innovation. It argues that in the case of chip design, a combination of pull, push and enabling factors is apparently creating a virtuous circle.[22] While pull factors explain what attracts design to particular locations, push and enabling factors highlight fundamental transformations in the methodology and organisation of chip design that tilt the balance in favour of geographical decentralisation.

As expected, supply-oriented forces attract global firms, especially the lower cost of employing a chip design engineer in Asia, which is typically between 10% and 20% of the cost in Silicon Valley.[23] However, demand-oriented factors are equally important. TNCs emphasise the need to relocate design to be close to the rapidly growing and increasingly sophisticated Asian markets for communications, computing and digital consumer equipment, and to be able to interact with Asia's lead users of novel or enhanced products or services. The main prize is the sheer size of China's market for IT hardware and services. China is the world's largest market for telecommunications equipment (wired and wireless), as well as a test bed for 3G and next generation wireless communication systems. It is also one of the most demanding markets for computing and digital consumer equipment. As most of that equipment is produced in China, the country has become the world's third largest market for semiconductors, generating substantial demand for chip design. To the degree that China succeeds in setting alternative standards, for instance for 3G mobile communications, chip design needs to take place on the spot to address the specific requirements of such standards. To penetrate Asia's growth markets, global IDMs (like Intel) and system companies (like IBM or Cisco) attempt to expand their 'platform leadership' strategies across the region.[24] For mobile communication systems, for instance, all major global system companies are expanding their Asian chip design centres to establish their own 'platform' designs as *de facto* standards in the region.

In the interviews, TNCs emphasised that policy factors, such as the provision of incentives and public goods (especially low-cost but high-quality infrastructure), can play an important role in attracting chip design to particular locations.[25,26] On the negative side, TNCs were concerned about obscure and unpredictably changing regulations and a weak IPR regime.[27] Asian firms acknowledged that policy factors played a powerful catalytic role in establishing critical infrastructure, support industries and design capabilities that enabled these firms to invest in and upgrade chip design.[28] Some Asian firms highlight peculiar features of product and factor markets that are shaped by diverse government policies and regulations. To take just one example: differences in Asian financial markets have led to diverse approaches to investment finance (e.g. debt, equity or retained earnings) that have shaped the volume and direction of investment in chip design. For instance, Taiwanese firms that rely primarily on equity report pressure to produce high margins as an important incentive to upgrade their design capabilities.[29]

Finally, Asian firms emphasise that progress in chip design owes much to concerted efforts by both governments and leading companies in these countries to establish new sources of innovation and global standards. Take telecommunications, where the Republic of Korea's four leading players (Samsung, SK Telecom, KT and LG) are all engaged in serious efforts to become major platform and contents developers for complex technology systems, especially in mobile communications. These efforts can build on considerable capabilities, accumulated in public research labs (like the Electronics and Telecommunications Research Institute, ETRI), as well as in R&D labs of the *chaebol*, to develop complex technology systems like TDX (a switching system) and communication systems that are based on the CDMA (code-division multiple access) standard. Furthermore, China's attempt to develop an alternative 3G digital wireless standard, called TD-SCDMA (time-division synchronous code-division multiple access), has created a powerful motivation to expand Asian electronic design activities for all strategic groups in the interview sample.[30]

4.1 Changes in methodology and organisation of chip design

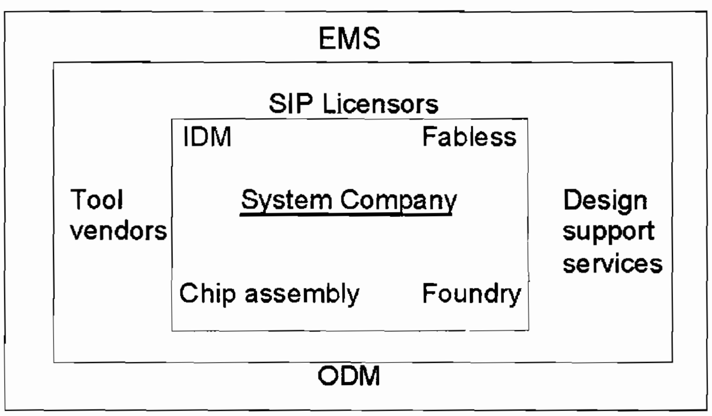
But what explains the fact that chip design, despite its extraordinary complexity, can now be conducted at multiple locations? And what makes it possible to exchange complex design knowledge when design teams that contribute to a particular project must communicate across borders and when they are located at distant locations, both geographically and in terms of widely different economic institutions? To answer these questions, the push and enabling factors, i.e. changes in the methodology and organisation of chip design, need to be examined.

Until the mid-1980s, system companies and IDMs did almost all their chip design in-house. Vertical integration corresponded to a focus of design on the individual component to be inserted on a printed circuit board. Since the mid-1990s, however, intensifying pressures to improve design productivity, combined with increasingly demanding performance features of electronic systems, have produced an upheaval in chip design methodology.[31] 'System-on-chip' design combines modular design[32] and design automation to move design from the individual component on a printed circuit board closer to 'system-level integration' on a chip (Martin and Chang, 2003).

SoC design has fostered vertical specialisation in project execution, enabling firms to disintegrate the design value chain as well as to disperse it geographically. This gave rise to complex, multi-layered GDNs with variable configurations, depending on the needs of a specific project. For instance, designing an embedded micro-controller for a mobile handset requires a different GDN configuration than the design of a graphic chip.

Three GDN layers can be distinguished (Figure 2). The *network core* encompasses five strategic groups of firms: The system company defines the concept, but may well outsource everything else. SoC design may take place within the system company, an IDM or a fabless chip design house (or a combination of these). And chip fabrication and assembly may be outsourced to specialised suppliers. A *secondary GDN layer* consists of suppliers of tools (for EDA; verification; and chip testing), SIP licensors and design implementation services. And a *third layer* may involve system contract manufacturers (both EMS and ODM).

Figure 2 Global design network – multiple layers (see online version for colours)



Source: Ernst (2005a)

Initially, vertical specialisation loosened the bonds between design and fabrication. This process started with ASIC design, where the goal was to avoid the high cost and time required to design a full-custom IC.[33] An important catalyst was the establishment of Taiwan Semiconductor Manufacturing Co. (TSMC) in 1987 as a provider of contract chip fabrication (silicon foundry) services for fabless design houses that outsource chip fabrication and target specialised niche markets. Until the early 1990s, GDNs were centred on the well-known symbiotic fabless/foundry relationship, and hence retained a relatively simple structure.

4.2 Huge number and variety of design teams involved in one project

Over time, however, vertical specialisation has increased the number and variety of GDN participants, business models and design interfaces, bringing together design teams from companies that drastically differ in size, market power, location and nationality. Take a SoC design network described by one interview respondent: a Chinese system company that defines the system architecture; a Taiwanese EMS that is responsible for contract manufacturing of the electronic equipment; an American IDM that provides a design platform; a European SIP provider; fabless design houses from the USA and Taiwan Province of China; foundries from Taiwan Province of China, Singapore and China; chip packaging companies from Taiwan Province of China and China; tool vendors for design automation and testing from the USA and India; and design support service providers from various Asian countries.

The interviews show that geographic proximity (for instance through clustering in the established centres of excellence in the USA or Europe) can become a disadvantage when a particular chip design project requires a large number of contributors (users and producers of innovation) with diverse knowledge sets and capabilities. For TNCs that are involved in chip design, it becomes increasingly costly to bring together a large group of diverse people at one location, and to keep the group there. When concentrated in one location, especially in the home country, such design groups may become too powerful, which may constrain productivity growth. This provides yet another powerful rationale for TNCs to offshore chip design to Asia.

The interviews also show that skill requirements and work organisation are of increasing importance as push factors. TNCs emphasise that both the USA and Europe have failed to train enough engineers for the next generation, giving rise to a serious skills bottleneck. More and more Asian governments are pursuing policies to increase the supply of well-educated and experienced engineers, scientists and managers, contributing to evolving global markets for knowledge workers. As a result, engineers in some Asian countries (especially Taiwan Province of China, Republic of Korea, Singapore, Malaysia, as well as China and India) are trained using the latest tools and methodologies. This is made possible by the emergence of a global market for education and training for specialised bottleneck skills in engineering and management. Asia's leading electronics exporting countries have been quick to develop their own private and public design training institutions to accelerate the development of new specialised chip and system design clusters. These training efforts are especially dynamic in India and North East Asia. And they are showing results, attracting support from leading EDA tool vendors. Once Asian designers have gained practical experience, they may have an advantage over designers in the traditional centres of design excellence in the USA.

4.3 Demand for greater workloads

Equally important, TNCs are seeking to increase workloads and to place a cap on the growth of remuneration of design engineers, in an effort to reverse the rapid growth that took place during the New Economy boom of the 1990s. Today, SoC designers "work six days per week, twelve hours per day, with intense pressures to meet the time-to-market requirements for design" (IBS, 2002, p.42). But as pressure grows in the USA to declare stock options as expenditures, it is difficult to see why designers there would be willing to keep up with such health-destroying workloads. It may be different, however, in Taiwan Province of China and China, where the system of personal income taxation enables semiconductor personnel to receive company stock and options as compensation in a manner which results in little or no actual income or capital gains tax being paid when the stock is sold. As a result, Taiwanese and Chinese firms arguably "have a competitive advantage … with respect to competition for talent that other firms cannot match" (Howell et al., 2003, IV).[34]

But once GDNs are extended to include Asia's emerging new specialised electronics industry clusters, there are very demanding requirements for knowledge sharing. Not only are the Asian locations geographically far from Silicon Valley, but they also differ substantially from the home country locations of TNCs, in terms of their stage of development and their economic institutions. For instance, vast differences continue to exist in labour markets, education systems, corporate governance, and legal and regulatory systems; these differences complicate transactions and even more so the knowledge exchange that is needed to support these transactions.

The final link in the analysis is the role played by enabling factors. An important finding of the interviews is that the ICT-enhanced information management, which reduces the cost of communication; helps to codify knowledge through tools and cell libraries; enables remote control; and facilitates exchange of tacit knowledge through audio-visual media, may facilitate the exchange of design knowledge across diverse design communities that are not co-located. A second enabling factor for knowledge exchange is transnational knowledge communities (Saxenian, 2002), comprising professional peer group networks, and Asia's large Diaspora of skilled migrants and IT mercenaries. The interviews show that these networks help to exchange complex design knowledge, provide much needed experience, facilitate links with markets and financial institutions, and can become an important source of reverse brain drain.

5 Conclusions

This paper demonstrates that internationalisation of innovation has driven vertical specialisation (i.e. outsourcing and offshoring) deeper and deeper into the innovation value chain. This has created new challenges and opportunities for industrial policies to attract and expand R&D investments by TNCs in Asia's electronics industry. Opportunities result from the increasingly fine-grained division of innovative labour, and the emerging global markets for technology and knowledge workers. In principle, this creates new opportunities for the international sourcing of key component technologies and scarce specialised skills. On the low end, this may enable local suppliers to produce specialised innovation services, like the design implementation services, described in the case study on chip design. But there are also substantial opportunities for upgrading local innovative activities, either by increasing the complexity of chip design tasks, or by moving up into conceptualisation (i.e. the specification of system architectures or applications).

In short, internationalisation of innovation is likely to accelerate Asia's transformation beyond the 'global factory' model to an important location for innovation offshoring. However, massive challenges must be mastered before Asia's leading electronics exporting countries can exploit the above opportunities. Such challenges result from the very demanding requirements that locations need to fulfil in order to qualify for R&D investment by TNCs. For instance, TNCs routinely expect access to high-quality but low-cost infrastructure and information and communication systems. TNCs also expect streamlined administrative procedures that facilitate smooth supply chain management and quick adjustments to changes in markets and technology. Equally important are efficient support industries and services with certified procedures that guarantee world-class quality standards and short time-to-market cycles.[35]

Ajzen and Madden (1986) is not cited in the text. Please provide citation in the text or else delete the publication details from the reference list. In short, the new geography of GINs is not a flatter world. Instead, concentrated network dispersion gives rise to a handful of new, but very diverse, innovation hubs in Asia. It is still an open question whether network integration is a poisoned chalice or whether it will reduce entrenched barriers to innovation. Much depends on policies to strengthen domestic innovation systems.

There is, however, room for cautious optimism. Innovation in Asia may develop faster than most observers predict. Asia dominates new TNC investments in R&D labs that are attracted by Asia's rapidly growing markets and its national innovation policies. Most important, however, is the amazing speed of learning, especially in China (Ernst and Naughton, 2008).

References

Armbrecht, F.M.R. (2003) *Citing Industrial R&D in China: Notes from Pioneers,* Slide presentation, Industrial Research Institute (IRI), Arlington, VA.

Arora, A., Fosfuri, A. and Gambardella, A. (2001) *Markets for Technology. The Economics of Innovation and Corporate Strategy,* MIT Press, Cambridge, MA.

Baldwin, C.Y. and Clark, K.B. (2000) *Design Rules: The Power of Modularity,* MIT Press, Cambridge, MA.

Barney, J.B. (1991) 'Firms resources and sustained competitive advantage', *Journal of Management,* Vol. 17, pp.99–120.

Baumol, W.J. (2002) *The Free-Market Innovation Machine. Analyzing the Growth Miracle of Capitalism,* Princeton University Press.

Borrus, M., Ernst, D. and Haggard, S. (2000) 'Cross-border production networks and the industrial integration of the Asia-Pacific region', in Borrus, M., Ernst D. and Haggard, S. (Eds): *International Production Networks in Asia. Rivalry or Riches?,* Routledge, London.

Brusoni, S. (2003) 'Authority in the age of modularity', *SPRU Electronic Working Paper Series No. 101,* Freeman Centre, University of Sussex.

Callan, B., Costigan, S.S. and Keller, K.H. (1997) *Exporting US High Tech. Facts and Fiction about the Globalization of Industrial R&D,* Council on Foreign Relations, New York.

Cantwell, J. (1995) 'The globalisation of technology: what remains of the product cycle model?', *Cambridge Journal of Economics,* Vol. 19, pp.155–174.

Cantwell, J. and Iammarino, S. (2003) *Multinational Corporations and European Regional Systems of Innovation*, Routledge, London and New York.

Chang, P.-L. and Tsai, C.-T. (2002) 'Finding the niche position – competition strategy of Taiwan's IC design industry', *Technovation*, Vol. 22, No. 2, pp.101–111.

Chesbrough, H.W. (2003) *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Harvard Business School Press, Boston, MA.

Christensen, C.M. (1997) *The Innovator's Dilemma. When New Technologies Cause Great Firms to Fail*, Harvard Business School Press, Boston, MA.

Coombs, R. and Georghiou, L. (2002) 'A new "industrial ecology"', *Science*, Vol. 296, No. 5567, p.471.

Dahlman, C.J. and Aubert, J.E. (2001) *China and the Knowledge Economy*, World Bank Institute, Washington, DC.

Dalton, D.H. and Serapio, M.G. (1999, September) *Globalizing Industrial Research and Development*, Office of Technology Policy, US Department of Commerce.

Dunning, J.H. (1998) 'Globalization, technology and space', in Chandler, A.D., Hagström, P. and Sölvell, Ö. (Eds): *The Dynamic Firm: The Role of Technology, Strategy, Organization, and Regions*, Oxford University Press.

Ernst, D. (1994) *What are the Limits to the Korean Model? The Korean Electronics Industry under Pressure*, A BRIE Research Monograph, The Berkeley Roundtable on the International Economy, University of California, Berkeley, CA.

Ernst, D. (1997) *From Partial to Systemic Globalization. International Production Networks in the Electronics Industry, Report to the Sloan Foundation, published as The Data Storage Industry Globalization Project Report 97–02*, Graduate School of International Relations and Pacific Studies, University of California, San Diego, CA.

Ernst, D. (2000, August) 'Inter-organizational knowledge outsourcing. What permits small Taiwanese firms to compete in the computer industry?', *Asia Pacific Journal of Management* (Special Issue on Knowledge Management in Asia), Vol. 17, No. 2, pp.223–256.

Ernst, D. (2002a) 'Global production networks and the changing geography of innovation systems. Implications for developing countries', *Economics of Innovation and New Technologies*, Vol. 9, No. 6, pp.497–523.

Ernst, D. (2002b) 'The economics of electronics industry: competitive dynamics and industrial organization', in Lazonick, W. (Ed.): *The International Encyclopedia of Business and Management (IEBM) Handbook of Economics*, International Thomson Business Press, London, pp.319–339.

Ernst, D. (2003) 'Digital information systems and global flagship networks: how mobile is knowledge in the global network economy?', in Christensen, J.F. (Ed.): *The Industrial Dynamics of the New Digital Economy*, Edward Elgar, Cheltenham, pp.151–178.

Ernst, D. (2004) 'Global production networks in East Asia's electronics industry and upgrading perspectives in Malaysia', in Yusuf, S., Altaf, M.A. and Nabeshima, K. (Eds): *Global Production Networking and Technological Change in East Asia*, a co-publication of the Oxford University Press and World Bank, Washington, DC, pp.89–158.

Ernst, D. (2005a) 'Complexity and internationalisation of innovation: why is chip design moving to Asia?', *Journal of Innovation Management* (Special Issue in honour of Keith Pavitt), Vol. 9, No. 1, pp.47–73.

Ernst, D. (2005b) 'Limits to modularity – reflections on recent developments in chip design', *Industry and Innovation*, Vol. 12, No. 3, pp.303–335.

Ernst, D. (2005c) 'The new mobility of knowledge: digital information systems and global flagship networks', in Latham, R. and Sassen, S. (Eds): *Digital Formations. IT and New Architectures in the Global Realm*, The US Social Science Research Council, Princeton University Press, Princeton and Oxford, pp.89–114.

Ernst, D. (2005d) 'Pathways to innovation in Asia's leading electronics-exporting countries: a framework for exploring drivers and policy implications', *International Journal of Technology Management* (Special Issue on Competitive Strategies of Asian High-Tech Firms), Vol. 29, No. 1/2, pp.6–20.

Ernst, D. (2006) *Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks*, East-West Center Special Reports Number 10 (jointly published with the US-Asia Pacific Council). Available online at: http://www.eastwestcenter.org/pubs/2006

Ernst, D. (2007a) 'Innovation offshoring – root causes of Asia's rise and policy implications', in Palacios, J.J. (Ed.): *Multinational Corporations and the Emerging Network Economy in the Pacific Rim*, Routledge, London. Co-published with the Pacific Trade and Development Conference (PAFTAD).

Ernst, D. (2007b) 'Beyond the "global factory" model: innovative capabilities for upgrading China's IT industry', *Technology and Globalization*, Vol. 3, No. 4, pp.437–460.

Ernst, D. (2008a) Can Chinese IT firms develop innovative capabilities within global knowledge networks?, in Hancock, M.G., Rowen, H.S. and Miller, F.W. (Eds): *China's Quest for Independent Innovation*, Shorenstein Asia Pacific Research Center and Brookings Institution Press.

Ernst, D. (2008b) 'Upgrading through innovation in a small network economy: insights from Taiwan's IT industry', *Economics of Innovation and New Technologies* (in press).

Ernst, D., Ganiatsos, T. and Mytelka, L. (Eds) (1998) *Technological Capabilities and Export Success – Lessons from East Asia*, Routledge, London.

Ernst, D. and Guerrieri, P. (1998, June) 'International production networks and changing trade patterns in East Asia. The case of the electronics industry', *Oxford Development Studies*, Vol. 26, No. 2, pp.191–212.

Ernst, D. and Kim, L. (2002) 'Global production networks, knowledge diffusion and local capability formation', *Research Policy* (Special Issue in honour of Richard Nelson and Sydney Winter), Vol. 31, No. 8/9, pp.1417–1429.

Ernst, D. and Lundvall, B.A. (2004) 'Information technology in the learning economy – challenges for developing countries', in Reinert, E.S. (Ed.): *Globalization, Economic Development and Inequality. An Alternative Perspective*, Edward Elgar, Cheltenham. Available online at: http://www.druid.dk/wp/pdf_files/97-12.pdf

Ernst, D., Mytelka, L. and Ganiatsos, T. (1998) 'Export performance and technological capabilities – a conceptual framework', in Ernst, D., Ganiatsos, T. and Mytelka, L. (Eds): *Technological Capabilities and Export Success – Lessons from East Asia*, Routledge, London, Chapter 1.

Ernst, D. and Naughton, B. (2005, August) 'China's emerging industrial economy – insights from the IT industry', paper prepared for the *East-West Center Conference on China's Emerging Capitalist System*, Honolulu, Hawaii.

Ernst, D. and Naughton, B. (2008, forthcoming) *Building Capabilities within Global Networks – China's Upgrading and Innovation in the IT Sector*, Manuscript, East-West Center, Honolulu, Hawaii.

Ernst, D. and O'Connor, D. (1992) *Competing in the Electronics Industry: The Experience of Newly Industrialising Economies*, Development Centre Studies, OECD, Paris.

Ernst, D. and Ravenhill, J. (2000) 'Convergence and diversity: how globalization reshapes Asian production networks', in Borrus, M., Ernst, D. and Haggard, S. (Eds): *International Production Networks in Asia: Rivalry or Riches?*, Routledge, London.

European Defence Agency (EDA) Consortium (2004, August) *Market Statistics Service Survey*, San Jose, CA.

Farrell, D., Laboissiere, M.A. and Rosenfeld, J. (2005) 'Sizing the emerging global labor market', *The McKinsey Quarterly*, No. 3. Available online at: http://www.mckinseyquarterly.com/article_page.aspx?ar=1635&L2=1&L3=106

Gassmann, O. and Zheng, H. (2004) 'Motivations and barriers of foreign R&D activities in China', *R&D Management*, Vol. 34, No. 4, pp.423–437.

Gawer, A. and Cusumano, M.A. (2002) *Platform Leadership. How Intel, Microsoft and Cisco Drive Industry Innovation*, Harvard Business School Press, Boston, MA.

Gereffi, G. (1994) 'The organization of buyer-driven global commodity chains: how US retailers shape overseas production networks', in Gereffi, G. and Korzeniewicz, M. (Eds): *Commodity Chains and Global Capitalism*, Praeger, Westport, CT, pp.95–122.

Gereffi, G. and Memedovic, O. (2003) *The Global Apparel Value Chain – What Prospects for Upgrading by Developing Countries*, UNIDO Sectoral Study, UNIDO, Vienna.

Granstrand, O., Hakanson, L. and Sjoelander, S. (1993) 'Internationalization of R&D – a survey of some recent research', *Research Policy*, Vol. 22, pp.413–430.

Granstrand, O., Patel, P. and Pavitt, K. (1997) 'Multi-technology corporations: why they have "distributed" rather than "distinctive core" competencies', *California Management Review*, Vol. 39, No. 4, pp.8–25.

Grindley, P.C. and Teece, D.J. (1997) 'Licensing and cross-licensing in semiconductors and electronics', *California Management Review*, Vol. 39, No. 2, pp.8–41.

Hobday, M. (1995) *Innovation in East Asia: The Challenge to Japan*, Edward Elgar, Aldershot.

Howell, T., Brent, R., Bartlett, L.N., William, A.H. and Howe, R. (2003, October) *China's Emerging Semiconductor Industry*, study prepared by Dewey Ballantine LLP for the Semiconductor Industry Association, San Jose, CA.

Iansiti, M. (1997) *Technology Integration: Making Critical Choices in a Dynamic World*, Harvard Business School Press, Boston, MA.

Iansiti, M. and West, J. (1997) 'Technology integration: turning great research into great products', *Harvard Business Review*, No. 5–6, pp.69–79.

IBS (2002) *Analysis of the Relationship between EDA Expenditures and Competitive Positioning of IC Vendors. A Custom Study for EDA Consortium*, International Business Strategies, Inc.

iSuppli (2003) *China's Fabless Firms Race Beyond Foundation Stage*, report prepared by Byron Wu, iSuppli, El Segundo, CA.

ITRS (2004) *International Technology Roadmap for Semiconductors 2003 Edition*, Semiconductor Industry Association, Austin, TX.

Kogut, B. and Zander, U. (1993) 'Knowledge of the firm and the evolutionary theory of the multinational corporation', *Journal of International Business Studies*, Vol. 24, No. 4, p.625.

Kuemmerle, W. (1996) *Home Base and Foreign Direct Investment in R&D*, PhD Dissertation, Harvard Business School, Boston, MA.

Kuemmerle, W. (1997) 'Building effective R&D capabilities abroad', *Harvard Business Review*, No. 3–4, pp.61–70.

Li, J. and Jing, Z. (2003) 'Explaining the growth of international R&D alliances in China', *Managerial and Decision Economics*, No. 24, pp.101–115.

Linder, S.B. (1961) *An Essay on Trade and Transformation*, Almqvist and Wiksell, Uppsala.

Lu, Q. (2000) *China's Leap into the Information Age. Innovation and Organization in the Computer Industry*, Oxford University Press.

Martin, G. and Chang, H. (Eds) (2003) *Winning the SoC Revolution: Experiences in Real Design*, Kluwer, Boston, MA.

Mathews, J.A. (2002) *Dragon Multinational. A New Model for Global Growth*, Oxford University Press.

Mathews, J.A. and Cho, D.S. (2000) *Tiger Technology: The Creation of a Semiconductor Industry in East Asia*, Cambridge University Press.

Medcof, J.W. (1997) 'A taxonomy of internationally dispersed technology units and its application to management issues', *R&D Management*, Vol. 27, No. 4, pp.301–318.

Memedovic, O. (2005) *Inserting Local Industries into Global Value Chains and Global Production Networks: Opportunities and Challenges for Upgrading*, UNIDO Working Paper, Vienna.

Moore, G.E. (1965) 'Cramming more components onto integrated circuits', *Electronics*, Vol. 38, No. 8, pp.114–117.

Nanda, V. (2003) *IC Design House Survey 2003: Taiwan*, Electronic Engineering Times Taiwan. Available online at: www.eettaiwan.com

National Science Board (2004) *Science and Engineering Indicators 2004*, National Science Foundation, Arlington, VA.

National Science Board (2008) *Science and Engineering Indicators 2008*, National Science Foundation, Arlington, VA.

Naughton, B. and Segal, A. (2002) 'Technology development in the new millennium: China in search of a workable model', in Keller, W. and Samuels, R. (Eds): *Crisis and Innovation: Asian Technology after the Millennium*, Cambridge University Press, Cambridge, MA.

Ng, F. and Yeats, A. (2003, June) *Major Trade Trends in East Asia. What are Their Implications for Regional Cooperation and Growth?*, World Bank Policy Research Working Paper No. 3084, Washington, DC.

OECD (2007) *Review of China's Innovation Policy*, OECD, Paris.

Patel, P. and Pavitt, K. (1991) 'Large firms in the production of the world's technology: an important case of non-globalisation', *Journal of International Business Studies*, Vol. 22, No. 1, pp.1–21.

Pavitt, K. (1999) *Technology, Management and Systems of Innovation*, Edward Elgar, Cheltenham.

Penrose, E. (1995) *The Theory of the Growth of the Firm*, 3rd ed., Oxford University Press (original edition published in 1959 by New York, Wiley).

Reddy, P. (2000) *Globalization of Corporate R&D. Implications for Innovation Systems in Host Countries*, Routledge, London and New York.

Saxenian, A. (2002) 'The silicon valley connection: transnational networks and regional development in Taiwan, China and India', *Industry and Innovation* (Special Issue on 'Global Production Networks', guest editors: D. Ernst and Linsu Kim), Vol. 9, No. 2, pp.183–202.

Shen, X. (1999) *The Chinese Road to High Technology. A Study of Telecommunications Switching Technology in the Economic Transition*, St. Martin's Press, New York.

SIA (1999) *International Technology Roadmap for Semiconductors, 1999 Edition*, Semiconductor Industry Association, San Jose, CA.

Stigler, G. (1951) 'The division of labor is limited by the extent of the market', *Political Economy*, Vol. 59, pp.185–193.

UNCTAD (2005) *UNCTAD Survey on the Internalization of R&D*, Occasional Note, 12 December 2005, Geneva.

Vonortas, N.S. (1997) *Cooperation in Research and Development*, Kluwer, Boston, MA.

Von Zedtwitz, M. (2004) 'Managing foreign R&D labs in China', *R&D Management*, Vol. 34, No. 4, pp.439–452.

Von Zedtwitz, M. and Gassmann, O. (2002) 'Market versus technology drive in R&D internationalization: four different patterns of managing research and development', *Research Policy*, Vol. 31, No. 4, pp.569–588.

Walsh, K. (2003) 'Foreign high-tech R&D in China. Risks, rewards, and implications for US-China relations', paper prepared for *The Henry L. Stimson Center*, Washington, DC.

The Yearbook of World Electronics Data (2006) America, Japan and Asia Pacific.

Notes

1 Throughout this paper, 'Asia' excludes Japan.

2 See Gereffi (1994), Ernst (1997), Borrus et al. (2000), Ernst and Ravenhill (2000), Ernst (2000), Mathews (2002).

3 See Memedovic (2005), Gereffi and Memedovic (2003), Ernst and Kim (2002), Hobday (1995), Ernst, Mytelka, et al. (1998), Ernst and O'Connor (1992).

4 For instance, a 1998 National Science Foundation study showed that over 50% of the post-doctoral students at MIT and Stanford were not US citizens, and that more than 30% of computer professionals in Silicon Valley were born outside the USA, most of them from India and China (quoted in National Science Board, 2004).

5 In 2000, 85% of global R&D expenditures were concentrated in only seven industrialised countries, with the USA occupying the leading position with 37% (Dahlman and Aubert, 2001, p.34).

6 The UNCTAD sample includes the first 300 firms of the 700 top R&D spenders, as identified by the R&D scoreboard, published annually by the British Department of Trade and Industry.

7 Penrose, 1995, Foreword, 3rd ed., *The Theory of the Growth of the Firm*, pp.16–17.

8 A particularly intriguing example is China's pioneering role in the development of the world's first commercially operated nuclear 'pebble bed' reactor that offers the hope of cheap, safe and easily expandable nuclear power stations ('China in drive for nuclear reactors', *Financial Times*, 8 February 2005, p.4). Within Asia, new innovation clusters have also emerged for broadband technology and applications in the Republic of Korea and Singapore; for mobile communications and digital consumer devices in Republic of Korea, Taiwan Province of China and China; and for software engineering and embedded software development in India.

9 The argument that technology and innovation can be the subject of a division of labour goes back to Stigler (1951). That widely quoted article argues that, as the extent of the market is increasing, the division of labour would also embrace innovation, leading to the rise of stand-alone R&D labs that would sell their research results to other parties.

10 Useful surveys are Reddy (2000, chap. 2), Medcof (1997), von Zedtwitz and Gassmann (2002).

11 According to the R&D director of a major TNC, "both the pace and the acceleration of innovation are startling. No one can predict the range of skills that will need to be amassed to create and take advantage of the next revolution but one. (And thinking about the next but one is what everyone is doing. The game is already over for the next.)" (quoted in Ernst and Lundvall, 2004).

12 Innovative capabilities are defined as the skills, knowledge and management techniques needed to design, produce, improve and commercialise 'artefacts', i.e. products, services, machinery and processes (Ernst, forthcoming).

13 Of course, hardly any company has ever relied on a completely closed, self-contained innovation system, except in times of war or in dictatorial societies. Chesbrough's concept of a closed innovation system highlights two stylised organisational routines that over time constrain the economic benefits from innovation. First, the firm creates ideas for the sole purpose of using them. And, second, the firm only uses ideas that have been created internally, the so-called 'not invented here' syndrome (Chesbrough, 2003, p.29). An open innovation system, on the other hand, requires that the corporation redefines its business model to commercialise technologies that it has at its disposal, both from external sources and through in-house development.

14 Gordon Moore's prediction, made in 1965, that economical density of integrated circuits will double roughly every one to two years, still holds (Moore, 1965).

15 The membership of the Industrial Research Institute (IRI) includes more than 240 leading global manufacturing TNCs that perform over two-thirds of the industrial R&D in the USA.

16 Interviews were conducted with parent companies and overseas affiliates for the US, Taiwanese and Korean firms, while for Chinese and Malaysian firms interviews were conducted with parent companies only. In China, the sample included State-Owned Enterprises (SOEs), collective enterprises and private technology firms.

17 Fabless chip design houses outsource chip fabrication and target specialised niche markets.

18 The interviews do not reveal whether these investments would complement or substitute for chip design investments elsewhere.

19 Chip design activities are typically divided into routine functions (design implementation) and stages of design that centre on conceptualisation (system/application specification).

20 "Architecture" refers to "the partitioning of the (computer) system into components of a given scope and related to each other functionally and physically through given interfaces. From a given architecture flows the design of components' functions and how they relate to each other…" (Gawer and Cusumano, 2002, p.18).

21 An important priority for future research is to explore the composition of these design centres with regard to the role played by local companies, foreign affiliates of TNCs and government institutions.

22 For a detailed analysis, see Ernst (2005a).

23 These cost comparisons typically include salary, benefits, equipment, office space and other infrastructure.

24 The overriding purpose of "platform leadership" strategies is to leverage the existing market power of industry leaders into the control of "systemic architectural innovations" (Gawer and Cusumano, 2002, p.39). A typical example is Intel's attempts to extend its control over microprocessors by creating widely accepted architectural designs that increase the processing requirements of electronic systems, and hence the market for Intel's microprocessors.

25 Similar findings are reported in Armbrecht (2003), von Zedtwitz (2004) and Walsh (2003).

26 The interviews did not address which specific incentives were most attractive, nor which countries were most aggressive in providing incentives. However, most interviewees mentioned aggressive incentives implemented in China. During the interview period, chips designed by foreign and domestic companies in China were eligible for a 14% VAT tax rebate, which lowered the effective tax rate to 3%, from the nominal rate of 17% on sales of imported and domestically produced chips. This policy, which created a powerful artificial cost advantage for domestically designed chips, was later abandoned under pressure from the US government.

27 Future research needs to explore whether and how a weak IPR regime is preventing TNCs from upgrading their design labs in Asia, or whether other motivations are overriding these concerns.

28 This supports earlier findings in the literature, e.g., Shen (1999), Lu (2000), Naughton and Segal (2002), Mathews and Cho (2000), Hobday (1995), Ernst, Ganiatsos, et al. (1998), Ernst and O'Connor (1992), Ernst (1994) and Ernst (2000).

29 Taiwanese firms develop "slightly more complex designs on average at slightly higher design productivity rates" than Chinese firms (Nanda, 2003, pp.11–12). However, even these relatively small differences in design complexity and productivity can provide substantial rewards: Taiwanese design houses were paid roughly three times as much as their Chinese counterparts.

30 Datang Telecom, a Chinese SOE, and the Research Institute of the Ministry of Information Industry developed the TD-SCDMA standard, with technical assistance from Siemens. To accelerate implementation, Datang has formed a series of collaborative agreements: a joint venture with Nokia, Texas Instruments, the Korean LG group and Taiwanese ODM (original design manufacturing) suppliers; a joint venture with Philips and Samsung; and a licensing agreement with STMicroelectronics that will provide the Chinese company with access to critical design building blocks (Ernst and Naughton, 2005).

31 Design methodology is the sequence of steps by which a design process will reliably produce a design 'as close as possible' to the design target, while maintaining feasibility with respect to constraints.

32 Modular design is a particular design methodology in which "parameters and tasks are interdependent within units (modules) and independent across them" (Baldwin and Clark, 2000, p.88).

33 An ASIC typically is composed of standard building blocks called cells that are designed to implement a specific customer application.

34 In Taiwan Province of China and China, employees of semiconductor firms who have received stocks as compensation are taxed on the face value of the shares, not the market value, which is often many times higher than the face value, given the rapid growth of semiconductor firms in both countries.

35 For a theoretical framework, see Ernst and Kim (2002), Ernst (2002a) and Ernst (2007a). For a detailed analysis of China's challenge, see Ernst (2007b), Ernst (2008a) and Ernst and Naughton (2008). For Taiwan, see Ernst (2008b).