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EAST-WEST CENTER

Economics Series

No. 95, February 2008

Innovation Offshoring and Asia's 'Upgrading through Innovation' Strategies

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A revised version will be published in *Transnational Corporations, 2008, special issue Esssays in Honour of Sanjaya Lall.*

Innovation Offshoring and Asia's 'Upgrading through Innovation' Strategies

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Acknowledgements
I gratefully acknowledge ideas, comments and suggestions from Rajah Rasiah, the late Kim Linsu, Mark Borthwick, Richard Baker, William Lazonick, Tain-Jy Chen, John Cantwell, Bengt-Ake Lundvall, Barry Naughton, Shin-Horng Chen, Michael Best and Boy Luethje. At the East-West Center, I am grateful to Charles Morrison and Nancy Lewis for supporting this research. The Volkswagen Foundation provided generous funding for research on the offshoring of chip design. Kitty Chiu, Peter Pawlicki and Rena Tomlinson provided excellent research assistance.

Introduction

I first met Sanjaya Lall in the late 1970s, when we were both consultants for Surendra J. Patel's technology division at UNCTAD. Since then, his writings have had a lasting impact on my research. This is true in particular for Sanjaya's pioneering study on technological capabilities, prepared for the OECD Development Centre (Lall, 1990).

For me, a defining characteristic of Lall's work is his insistence that industrialization in Asia has been shaped by the interplay of *global* forces (embodied in international trade and foreign direct investment) and *local* strategies (pursued by host country firms and governments).

Specifically, Lall's research has taught me the following important lessons. First, integration into the global economy and FDI can act as important catalysts for change, but there is likely to be a "divergence between the private interests of the multinational company and the social interests of the host economy in terms of long-term technology development." (Lall and Urata, 2003:p4). Policies need to be based on a profound understanding of these divergent interests, and they need to adjust to changes in MNC strategies.

Second, liberalization of trade and investment should not be equalized with a retreat of the state. "A consideration of the technology development process at the micro-level provides a strong and valid economic case for industrial policy, and the East Asian case provides the empirical backing." (Lall, 2000: p. 13,14)

Third, as a country becomes more exposed to globalization, this increases the importance of local capabilities and innovation, "because technical efficiency in each location becomes the final determinant of success"(Lall, 2003: p.46). The more a country moves up the industrial ladder, the more important are advanced capabilities and innovation. Lall emphasizes that, while FDI can facilitate the development of basic operational capabilities, required for the production and use of foreign technology, they "may be less efficient means of deepening capabilities, particular into design and innovation." (Lall, 2003: p.13).

Fourth, the key to success is to generate a virtuous circle of institutions and firm-level capabilities. Lall highlights the following prerequisites for successful industrial upgrading: "skill development, industrial specialization, enterprise learning and institutional change are needed to create *cumulative* and *self-reinforcing processes* to promote further learning…" (ibid, p. 47)

Fifth, Lall's writings consistently emphasize that diversity is possible in the strategies that host countries use to foster industrial upgrading. Lall's extensive research on Asian industrial policies shows that "each of these policies has been successful in its own way in boosting export competitiveness, though each faces different… (risks and)… strategic challenges." (Lall, 2003: p.4). There are no "one-best way"-solutions. Instead, policies and strategies need to be continuously adjusted to the vagaries of business cycles and, even more important, to the structural transformations of markets and technology.

In this paper, I use Lall's framework to interpret findings of my own research on an important recent development – the offshoring of innovation to Asia (Ernst, 2006a, 2005a) and its impact on the region's attempts to upgrade its industries through innovation.[1] I demonstrate that Lall's framework remains valid, once globalization extends beyond markets for goods and finance into markets for technology and knowledge workers.[2] I show however that there is reason for cautious optimism that innovation offshoring may facilitate host country efforts to develop their own innovative capabilities.

The paper is primarily a think piece that seeks to sketch a roadmap for extending Lall's research agenda to cope with the challenges that result from fundamental changes in the economics of innovation and the resultant adjustments in corporate strategies and government policies that give rise to innovation offshoring. The evidence used to support my arguments draws on original research as well as secondary literature.

Section one of the paper provides a brief sketch of characteristics and drivers of innovation offshoring. In section two, I introduce a concept of 'industrial upgrading' that links specialization with firm-level and industry-level upgrading and high integration into global networks. Section three, finally, discusses generic policy suggestions.

1. Characteristics and Drivers of Innovation Offshoring

It is widely assumed that innovation, in contrast to most other stages of the value chain, is highly immobile- that it remains tied to specific locations, despite a rapid geographic dispersion of markets, finance and production (e.g., Archibugi and Michie, 1995). Only a decade ago, research on the geographical distribution of patents demonstrated that innovative activities of the world's largest firms were among the least internationalized of their functions (Patel and Pavitt, 1991). It was argued that innovation within the firm was and would always be highly localized because it usually requires dense exchange of knowledge (much of it tacit) between the users and producers of the resultant new technologies. Attempts to explain such spatial stickiness of innovation have focused on the *dynamics* of spatial agglomeration within localized innovation clusters (e.g., Feldman, 1999; Porter and Solvell, 1998; Jaffe et al, 2000).

There is no question that the demanding requirements of managing complex innovation projects tend to concentrate innovation in the home country. However, research on globalization has clearly established that the center of gravity has shifted beyond the national economy (e.g., Dunning, 1998). International linkages proliferate, as markets for capital, goods, services, technology and knowledge workers are integrated across borders (Ernst, 2005c). While integration is far from perfect, especially in the latter two markets, it is nevertheless transforming the geography of innovation (Ernst, 2002a). As markets for technology and knowledge workers have globalized, fundamental changes have occurred in corporate innovation management-a gradual opening and networking of corporate innovation systems is giving rise to global innovation networks (GINs) that cut across firm boundaries and national borders.

There is ample evidence that global firms are expanding their overseas R&D. For instance, R&D of foreign affiliates of the world's leading global corporations has more

[1] 'Innovation' is defined as "new combinations of existing resources to create, change, improve, and commercialize products, services, processes and business models for market and social needs." (Ernst, 2007d)

[2] 'Knowledge workers' are defined to include science and engineering personnel, as well as managers and specialised professionals (in areas like marketing, legal services and industrial design) that provide essential support services to research, development and engineering.

than doubled, from $30 billion in 1993 to $65 billion in 2002, compared to a 44% growth of world business R&D (UNCTAD, 2005a).[3] This has resulted in an increase of the share of foreign affiliates in world business R&D from 10 to 15 percent.

As for Asia, its share in the overseas R&D by US firms has almost quadrupled, from three percent of a total of $12 billion in 1994 to close to 12% out of $20 billion in 2002 (Department of Commerce, 2004). And a recent UNCTAD survey of the world's largest R&D spenders shows that, by 2004, a handful of Asian countries had drastically increased their importance as destinations of international R&D (UNCTAD 2005 b).[4] The US and the UK continue to be the leading destinations-but China now is the third most important offshore R&D location, followed by India (6th) and Singapore (9th). More than half (57%) of the responding firms have at least one R&D facility in China, India or Singapore. And a 2006 *Economist Intelligence Unit* survey of 300 senior executives of leading global corporations finds that India and China are the 2nd and 3rd most important offshore R&D location (after the US and ahead of the UK).

Much of the R&D offshoring to Asia is concentrated in the electronics industry, with China dominating R&D for hardware, and India attracting R&D for software. As for non-equity forms of R&D internationalization ("offshore outsourcing"), China is now the third most important location (behind the US and the UK, but ahead of Germany and France), and India is ranked equal to Japan.

The same survey projects that the pace of R&D internationalization will accelerate-as many as 67% of the respondents to the UNCTAD survey stated that the share of foreign R&D is set to increase; only two percent indicated the opposite. In this new wave of R&D internationalization, large US corporations are likely to play a critical role-as they are planning to catch up with European companies in their reliance on R&D internationalization. Furthermore, Japanese and Korean firms are especially aggressive in their future plans, and are keen to move beyond their current low levels of R&D internationalization.

Asia is expected to receive much of the future R&D internationalization-with China being the most attractive location for future foreign R&D, ahead of the US and India. Leading global corporations also intend to expand their offshore outsourcing of R&D to Asia. And large global electronics firms report the most aggressive plans to expand innovation offshoring to Asia.

Case studies of company-specific global innovation networks (GINs) confirm these trends (Ernst, 2005a and 2006a). They show that GINs combine the geographic relocation of innovation ('offshoring') with changes in the boundaries of the firm ('outsourcing'). Global companies 'offshore' stages of innovation to overseas affiliates to tap into lower-cost pools of knowledge workers and to penetrate new large growth markets. Take Intel as an example (Ernst, 2007b). Its labs in Santa Clara, Folsom and Austin remain primary locations for core technology development and applied research, while Haifa (established in 1974) is focused on processor research and Nishny Novgorod on software development.

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[3] Calculated from OECD data base, drawing on data provided by 30 leading economies.

[4] The survey sample consist of the first 300 firms of the R&D scoreboard of the 700 top R&D spenders, published by the United Kingdom's Department of Trade and Industry. The low response rate of 22% indicates that major publicly listed global firms consider R&D to be a strategic function and a core determinant of stock market value, and are reluctant to share R&D-related information.

Intel has currently seven R&D labs in Asia (outside of Japan), but it is planning to expand rapidly both the number of labs and their headcounts. Bangalore, Intel's largest lab outside the United States, conducts leading-edge dual processor development. With a workforce of around 2,700, management plans a substantial expansion, most likely in second-tier cities that have lower labor costs than Bangalore. In Shanghai, Intel has recently expanded its R&D team to focus on applied research to identify new applications for China and other emerging markets.

The Bangalore lab of Texas Instruments (TI) indicates the depth of innovation offshoring to Asia (Ernst, 2007 IC design report). Established in 1985, it is TI's largest lab outside the United States. Since 1998, this lab has conducted integrated development projects for highly complex system-on-chip design. TI Bangalore's R&D projects closely interact with teams across TI's global innovation network. TI Bangalore now has the global mandate for developing or co-developing a broad portfolio of leading-edge chips (including digital signal processing chips, 3G wireless chipsets and dual-mode microprocessors).

But global firms also outsource some stages of innovation, especially those related to product development, to specialized offshore suppliers as part of complex *inter-firm* GINs. For instance, global brand leaders for laptops and handsets use design services provided by specialized contractors, the so-called 'original design manufacturers' (ODMs), mostly from Taiwan, for new product development (Ernst, 2007e).[5] In addition, global system companies (like IBM) and integrated device manufacturers (like Intel) are outsourcing to Asian design houses the development of specific design building blocks and design implementation services (Ernst 2005a, 2005b).

Over time, an increasing diversity of GINs has emerged, bringing together R&D teams from companies that drastically differ in size, business model, market power, location, and nationality. The flagship companies that control key resources and core technologies, and hence shape these networks, are still overwhelmingly from the US, Japan and the EU. However, there are also now network flagships from Asia (outside Japan).

An important feature of the global knowledge economy is that large Asian firms that compete in global markets, are also constructing their own (mostly intra-firm) GINs. Early pioneers included Korea's Samsung and Taiwan's Acer.[6] Those are now followed by companies from China and India. Take Huawei, China's leading telecommunications equipment producer, which has developed a web of project-specific collaboration arrangements with major suppliers of core components, such as Siemens (as part of China's TD-SCDMA project), 3Com (with a focus on sales and joint product development), as well as Intel and Qualcomm. And Huawei's own global innovation network now includes, in addition to six R&D centers in China, five major overseas R&D centers in the US (Plano/Texas and San Jose/California), Sweden (Kista/Stockholm),

[5] ODMs either implement a detailed set of design specifications provided by a global brand leader or they provide their proprietary integrated 'turnkey' solution to basic performance parameters requested by the brand leader.

[6] On Korean overseas R&D, see Youngsoo Kim (2000), Sachwald (2001) and Ernst (1994). For Taiwanese firms, see Chen, 2002 and Ernst, 2001a.

Moscow and the UK (as part of British Telecom's list of eight preferred suppliers for the overhaul of its UK fixed-line phone network).

Finally, an important new development is that smaller US high-tech companies, and even start-ups, are facing considerable pressures to engage in innovation offshoring. In fact, venture capitalists in Silicon Valley now require start-ups to present an "offshore outsourcing" plan as a precondition for receiving funding. The emerging business model is to keep strategic management functions like customer relations and marketing, finance, and business development in Silicon Valley, while increasingly moving product development and research work to offshore locations.

This has given rise to new models of innovation offshoring that frequently involve foreign-born engineers from Taiwan, China, and India. A typical example is a start-up company in Shangdi Information Industrial Base in Beijing's Haidian District that specializes in mixed-signal chip design (Ernst, 2007b). The founders are Chinese engineers who hold Ph.D. degrees from leading US universities and have worked as senior project managers in leading US semiconductor companies. The company has received venture capital funding for developing chip designs in both China and Silicon Valley.[7]

The result is that, instead of a few pre-eminent centers of innovation, like Silicon Valley, there are now multiple locations for innovation, and even lower-order or less developed centers can still be sources of innovation (Cantwell 1995: 172). This is true for instance for materials, especially nano-science, where China is emerging as a new global center of excellence.[8] China is also emerging as an important player in analytical chemistry, rice genomics and stem cell biology. And India's bright spots include pharma, biotech and bio-informatics, as well as software and chip design.

In chip design, for instance, it is possible to distinguish three types of competing offshore locations: advanced, catching-up and new locations. And within Asia, a handful of new, but rapidly expanding, clusters is emerging in places as diverse as Hsinchu, Taipei, Taichung and Tainan (in Taiwan); in Shanghai, the Yangtze River Delta, Beijing, Shenzhen, the Pearl River Delta and Xián (China); in Seoul and Taejong (South Korea); in Bangalore, Noida, Chennai, Hyderabad, Mumbai, Puneh and Ahmedabad (India); in Penang and Kuala Lumpur (Malaysia); and in Singapore (Ernst 2005a).

In essence, it is this proliferation of regions of innovation that defines what is new about the emerging global knowledge economy. New actors have entered the game, challenging the incumbent leaders and the rules that the incumbents have established for competition and innovation.

2. Industrial Upgrading and Global Network Integration

Asia's rise as the global factory provides a fascinating example for Lall's proposition that industrialization in this region has been shaped by the interplay of *global*

[7] A fully integrated design team in Beijing develops decoder chips customized for the new Chinese AVS (audio-video signal) standard. Of the more than 60 engineers at the Beijing facility, 90 percent hold at least Masters degrees. Five senior managers based in Santa Clara handle customer relations and provide design building blocks and tool vendors for design automation, testing, and verification.

[8] China ranks 3rd (after US and Japan) in the number of nanotech publications (Ernst, 2007f). And the Chinese Academy of Science is ranked fourth for nano-science citations (after UC Berkeley, MIT and IBM).

forces (embodied in international trade and foreign direct investment) and *local* strategies (pursued by host country firms and governments). But this framework can also be used to analyze Asia's 'upgrading-through-innovation' strategies.

The concept of "industrial upgrading" (IU) can serve as a focusing device for Asia's attempts to move beyond the "global factory" model and to unlock new sources of economic growth. The main objective is to exploit the productivity-enhancing potential of innovation, in order to avoid a race to the bottom that is driven solely by cost competition. Hence, in general terms, industrial upgrading must focus on improvements in specialization, local value-added, productivity, and forward and backward linkages, all of which necessitate a broad base of knowledge and innovation (Ernst and Lundvall, 2004).

I distinguish two aspects of industrial upgrading that are of greatest policy relevance: "firm-level upgrading" from low-end to higher-end products and value chain stages, and "industry-level linkages" with support industries, universities and research institutes.[9] "Firm-level upgrading" is the key dimension-Asian firms must develop the capabilities, tools and business models that will allow them to cope with the new challenges from innovation offshoring.

But for firm-level upgrading to succeed, upgrading must take place simultaneously at the level of "industry linkages." To broaden the pool of firms that are fit for sustained firm-level upgrading, strong support industries are required and dense linkages with universities and research institutes. The challenge is to enable firm-level and industry-level upgrading to interact in a mutually reinforcing way, so that both types of upgrading will give rise to a 'virtuous circle.'

Asia's industrial upgrading efforts also face a second challenge. As its companies are integrated into multiple global networks of corporate production and innovation and informal knowledge communities, it is obvious that international linkages are critical for industrial upgrading. Hence, we need to distinguish domestic ('local') and international ('global') elements.

Finding the right balance between firm-level and industry-level upgrading, and between domestic and international elements poses a continuous challenge for policy makers and corporate planners-the "right balance" is a moving target, it is context-specific and requires permanent adjustments to changes in markets and technology. I argue that all four elements hang together-a strategy that neglects one element at the detriment of the others is unlikely to create sustainable gains. The stronger the links

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[9] The other three forms of "industrial upgrading" discussed in the literature are: (i) inter-industry upgrading proceeding from low value-added industries (e.g. light industries) to higher value-added industries (e.g. heavy and higher-tech industries); (ii) inter-factor upgrading proceeding from endowed assets (i.e., natural resources and unskilled labor) to created assets (physical capital, skilled labor, social capital); and (iii) upgrading of demand within a hierarchy of consumption, proceeding from necessities to conveniences to luxury goods. See Ozawa (2000) for discussion of upgrading taxonomies. Most research has focused on a combination of the first two forms of IU, based on a distinction between low-wage, low-skill "sun-set" industries and high-wage, high-skill "sunrise" industries. Such simple dichotomies however have failed to produce convincing results, for two reasons (Ernst, 2001b): First, there are low-wage, low-skill value stages in even the most high-tech industry, and high-wage, high-skill activities exist even in so-called traditional industries like textiles. And second, both the capability requirements and the boundaries of a particular "industry" keep changing over time. An example is the transformation of the personal computer industry from an R&D-intensive high tech industry to a commodity producer that depends on the optimization of supply chain management.

between those four elements, and the better they interact, the greater are the chances that Chinese firms can shape markets, prices and technology road maps.

2.1. Domestic elements

On the domestic front, an essential prerequisite for industrial upgrading are institutions and incentives that facilitate innovation and the development of support industries, and that provide a sufficiently large pool of experienced and re-trainable knowledge workers with specialized skills. The role of institutions and incentives is well covered in the literature on ‘national innovation systems’ (e.g., Freeman, 1987; Nelson, 1993; Lundvall, 1992).[10] But we know less about the second equally important domestic element - how specialization in products and types of production may enhance the potential for industrial upgrading.

Specialization and upgrading potential

Specialization is an important indicator of the degree of industrial upgrading that a country or region can realistically expect to achieve. Specialization patterns reflect differences in product mix (e.g., homogeneous versus differentiated products), and in types of production (where I suggest to distinguish between ‘routine’ and ‘complex’ production).[11] These differences in specialization, in turn, give rise to divergence in the complexity of technology, demand patterns and market structures. Most importantly, differences in specialization shape a country’s (a region’s) upgrading potential, in terms of learning opportunities, capability requirements, value-added and linkages.

A critical policy issue is to identify conditions under which specialization and upgrading potential are linked by a *virtuous* rather than a *vicious* circle. In fact, a narrow specialization on homogenous products or on ‘modular’ production may well make sense at an earlier stage of development, as it matches with the then prevailing competitive advantages. Yet, this very same specialization may later on hinder a transition to differentiated products or ‘integrated’ production.

Product specialization

Homogenous products (“commodities”) have only a limited upgrading potential, in terms of learning opportunities, capability requirements, value-added and linkages. The opposite is true for differentiated products.

For our purposes, it is useful to establish a link with the product life cycle (PLC) theory.[12] Following Vernon (1966), differentiated products are typically associated with the early stage of the PLC, while homogenous products most likely to prevail during the

[10] That literature shows that peculiar features of economic structures and institutions offer quite distinct possibilities for learning and innovation, and hence shape the technological (or economic) performance of a country/region. The economic structure determines specialization (i.e. the product mix and the production process) and learning requirements (the breadth and depth of the knowledge base, tools and capabilities). Institutions, on the other hand, shape learning efficiency: they define how things are done and how learning takes place. An important concern is the “congruence” (Freeman, 1997:13) of different subsystems, which is necessary to create a *virtuous* rather than a *vicious* circle.

[11] I use these distinctions to move the research agenda beyond the popular, but somewhat schematic dichotomy of ‘Fordist mass production’ versus the ‘Post-Fordism Flexible Specialization’. For a detailed theoretical discussion, based on evidence from chip design, see Ernst (2005b).

[12] I am grateful to MIT’s Calestous Juma for suggesting this link.

late stage. Take the PC industry, a typical example of a ‘late-stage’ industry, which is an important sector of China’s and Taiwan’s IT industries. As a “commodity”, the PC has very limited upgrading potential. The root cause is that Intel and Microsoft are in almost complete control of the standards and technologies, with the result that return on innovation for PC vendors is low, while the cost of innovation is high.

By contrast, the scope for differentiation is broader for high-end handsets (especially smart phones) and for the mobile network industry. Both are examples of ‘early PLC stage’ industries that are important for Korea, Taiwan and China. While entry barriers are high in both industries, in terms of investment and technology, there are ample opportunities for new entrants to upgrade through innovation.

High entry barriers are accompanied by qualitative competition. This requires complex capabilities to understand customer needs and to provide integrated solutions. Without policy support in “industry-level” upgrading, Asian firms would be hard-pressed to cope with these demanding requirements.

At the same time, this is an industry where premium pricing is possible, at least in some market segments. To the degree that this translates into high profit margins, this facilitates investment in R&D. As system architectures and interface standards remain fluid and are evolving rapidly, there are many learning opportunities and Asian firms are under considerable pressure to develop their capabilities. Furthermore, the mobile network industry provides ample opportunities for creating value-added and for developing linkages (both domestic and international) with customers, suppliers of core components and technology, and private and public R&D partners.

Types of production

The potential for industrial upgrading also differs for different types of production. For “routine” production, the upgrading potential is obviously lower than for “complex” production that needs to combine diverse technologies and that may require customization, quick responses to changes in market and technology, and the provision of integrated solutions. The rewards for a transition to “complex” production can be high - if a firm successfully implements complex processes, it may benefit from premium pricing and significant profit margins, which in turn could provide sufficient funding for R&D. The downside, of course, is the substantially higher preparatory efforts that are necessary for successful entry into the more knowledge-intensive complex production.

Take chip design, where “routine” functions (‘design implementation’) are distinguished from “complex” stages of design that center on conceptualization, circuit architecture and system specification. The requirements for making the transition from design implementation to conceptualization are quite demanding. Entry barriers are extremely high, as design costs at the 90 nano-meter technology (the current best-practice) can be as high as $20 to 30 million (Ernst, 2005a). Intensifying pressures to improve design productivity, combined with increasingly demanding performance requirements for electronic systems have produced an upheaval in chip design methodology.[13] “System-on-chip“(SoC) design has moved design from the individual component on a printed circuit board closer to “system-level integration” on a chip.

[13] “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.

These new challenges are likely to impose quite far-reaching changes on industry structure, business models and firm organization, illustrating again how closely inter-related are firm-level and industry-level upgrading.

2.2. The International Dimension

This brings us to the critical importance of international linkages for Asia's 'upgrading through innovation' strategies. A "closed economy" assumption became unrealistic, once liberalization and information technology (IT) had drastically increased the international mobility of trade, finance and investment, giving rise to geographically dispersed ("fragmented") global production networks (Venables, 2006; Borrus, Ernst and Haggard, 2000; Ernst, 1997 and 2002b).

As production and innovation systems across the region are integrated into complex global network arrangements, it is obvious that industrial upgrading does not end at the national border. Nor should one assume that industrial upgrading occurs only if improved specialization generates dense forward and backward linkages *within* a particular region or within the national economy. Asia's integration into these networks has created cross-border linkages that need to be exploited by its industrial upgrading strategies.

Recent shifts in the global innovation system have even further increased the importance of international linkages for industrial upgrading. As globalization has been extended beyond markets for goods and finance into markets for technology and knowledge workers, this has increased the organizational and geographical mobility of innovation.

Global corporations are at the forefront of these developments. Profound changes are transforming their innovation management-an increasing vertical specialization ("fragmentation") of innovation gives rise to more open corporate innovation systems. For instance, a study conducted by IBM Global Business Services with leading global corporations finds that a combination of suppliers, partners and customers is a more significant source of innovations than a company's employees and far more important than in-house R&D (IBM, 2006).

According to the US National Science Board, "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, Volume I, page IV-36).

We have seen in section 1 that innovation offshoring is rapidly expanding and that much of the action now is in Asia (outside Japan). The region's main attractions include lower-cost knowledge workers, large and increasingly sophisticated markets, and policies aimed at developing innovative capabilities. Global companies "offshore" stages of innovation to Asian affiliates to tap into the lower-cost talent pool and innovative capabilities of the region's leading export economies.

A Poisoned Chalice?

There are concerns that such deeper network integration may be a poisoned chalice. It is feared that, apart from a few prestige projects that might provide limited short-term benefits, R&D by global corporations may not provide the means for upgrading the host country's industry to higher value-added and more knowledge-intensive activities.

Research on Taiwan demonstrates that this country, which is deeply integrated into global networks, is now confronted with massive challenges. Foreign R&D centers may well intensify competition for the limited domestic talent pool (Chang, Shih and Wei, 2006). Inward R&D by global industry leaders may also give rise to a reverse 'boomerang effect'-providing global firms with precious insights into business models and technologies developed by domestic firms. In addition, foreign R&D centers may have limited interest in sharing knowledge with domestic firms and R&D labs, except as part of strictly hierarchical linkages between a global brand marketer and its Taiwanese OEM/ODM suppliers (Chen, 2006; Chang, Shih and Wei, 2006).

Sometimes, the main purpose of foreign R&D centers is to act as bridgeheads for the "platform leadership strategy" of global industry leaders who seek to enhance and control patterns of innovation in an industry. The over-riding purpose of these strategies is to shape the product and technology roadmaps of platform users. Intel and Microsoft provide two typical examples. Intel, for instance, attempts to extend its control over microprocessors by creating widely used architectural designs that increase the processing requirements of electronic systems, and hence the market for Intel's microprocessors (Gawer and Cusumano, 2002).

In short, vigorous policies must be in place to reduce the potentially high opportunity costs of inward R&D investment that may result from "brain drain" (both domestic and international), when global firms are crowding out the local market for scarce skills. Other costs discussed in the literature include a possible deterrence effect of global labs on local R&D; the acquisition by global firms of innovative local companies; and the disproportionately high benefits that may accrue to a foreign parent company (UNCTAD, 2005a).

In an interesting study on Taiwan's upgrading challenges, Tain-Jy Chen (2004: 17) raises a particularly troubling question. He argues that new competitive challenges that arise from shifts in the global innovation system may substantially decrease the returns that Taiwanese firms have been able to reap from network integration.

Specifically, Chen argues that, as global competition is centered increasingly on the development of superior knowledge, "intellectual property," (the commercial embodiment of knowledge) will become more and more intensely guarded. Hence, successful latecomers like Taiwan may now face severe "IP barriers"-"technologically advanced countries can effectively use IP as a barrier to block the attempts by latecomers to enter new industries that are presumably more lucrative but not yet subject to cost competition" (ibid).

A persistent US-centric concentration of the sources of innovation provides American global industry leaders with a robust bargaining position for setting up 'IP barriers'. In 2002 for instance, all 15 leading companies with the best record on patent citations were based in the US, with nine of them in the IT sector[14]. The 700 largest R&D spenders (mostly large U.S. firms) account for 50% of the world's total R&D

[14] 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. Since 1985, the US "innovation score" has more than doubled, a rate far better than any other country (CHI/MIT, 2003).

expenditures and more than two-thirds of the world's business R&D. And 86% of global R&D takes place in industrialized countries, with the US occupying the leading position with 37% (Dahlman and Aubert, 2001).

There is no doubt that global industry leaders are developing increasingly sophisticated "IP barrier" strategies. An important example are the afore-mentioned "platform leadership" strategies. Equally important are attempts to "black box" technologies so that they "cannot be easily imitated by competitors because they are: (1) protected under intellectual property rights, such as patents, (2) made of complex materials, processes, and know-how that cannot be copied, or (3) made using unique production methods, systems, or control technologies." (Ernst, 2006b: 183).

New Opportunities for Knowledge Diffusion?

But it is important to recognize that innovation offshoring through global innovation networks may also provide Asian firms with better access to innovation management practices, tools, ideas and opportunities for innovation.

For instance, foreign R&D centers could become important catalysts for accelerated learning and capability development. Let us look again at Taiwan. Chang, Shih and Wei (2006) find that exposure to state-of-the-art innovation management practices of global R&D operations can improve innovation management in Taiwan firms and force them to be "more innovative."

And Shin-Horng Chen (2006:15) finds that the R&D intensity of foreign-owned affiliates in Taiwan's manufacturing industry has increased from 1.5% in 2002 to 1.9% in 2003.[15] He uses four case studies of foreign R&D centers to explore why this might have happened. Chen argues that foreign-owned subsidiaries with high export intensity and which rely on Taiwanese OEM/ODM suppliers "may need to devote more effort to R&D in order to effectively interact with their local suppliers" (ibid: 16). In turn, this requires that domestic R&D has reached a critical threshold so that it can "serve as a complement to, rather than a substitute for, the R&D activities of foreign affiliates."

But more fundamental forces are at work. We have seen that, in response to the globalization of markets for technology and knowledge workers, global corporations are under tremendous pressure to tap into new sources of knowledge and innovation that are located in emerging lower-cost high tech regions, especially in Asia. Global firms expect that innovation offshoring will provide them with a powerful new source of competitive advantage-they hope that they can now quickly generate more and higher-value innovation at lower cost.

We know from the study of global production networks that the exchange of knowledge is the necessary glue that enables these networks to grow (Ernst, 2005c). This may force global firms to be more willing to engage in greater knowledge sharing. In my view, there are four reasons for cautious optimism.[16]

First of all, fundamental changes in competitive dynamics have made it more difficult for global firms to protect technology leadership positions through "IP barrier" strategies. This is especially true for hi-tech industries. For instance, R&D-intensive

[15] This calculation uses data provided by the Investment Commission of Taiwan's Ministry of Economic Affairs.

[16] Future research should systematically examine the specific conditions for enhancing the scope for knowledge diffusion.

sectors of the IT industry are exposed to intense price competition from a very early stage in their product life cycle (Ernst, 2002b).

Competition in these industries is driven by the speed of new product introduction, with the result that product life cycles become shorter and shorter.[17] Only those companies thrive that succeed in bringing new products to the relevant markets ahead of their competitors. Of critical importance for competitive success is that a firm can build specialized capabilities quicker and at less cost than its competitors (Kogut and Zander, 1993).

With short product cycles, it is very difficult to avoid periodic mismatches between supply and demand. Each time supply overshoots demand, price wars break out. At the same time, however, performance requirements for electronics systems become increasingly demanding. The convergence of digital computing, communication and consumer devices has produced electronic systems that all strive to become lighter, thinner, shorter, smaller, faster and cheaper, as well as more multi-functional and less power-consuming. Hence, IT producers must combine cost leadership with technology leadership and speed-to-market, a combination that can threaten even apparently unbeatable market leaders.

In addition, the success of the shareholder revolution and the growing role of private equity investors are forcing global IT companies to maximize their return-on-investment (ROI) across the value chain. To issue "buy" recommendations, analysts expect a firm's ROI to exceed, during each quarter, the adjusted market average. To achieve this goal, analysts have identified a new focus for restructuring strategies-firms must reduce the wide productivity gap between manufacturing and R&D, by drastically reducing R&D costs.

No firm, not even a global market leader like Intel, can mobilize internally all the diverse resources, capabilities, and bodies of knowledge that are necessary to fulfill this task. This explains why global firms have little choice but to offshore innovation through global innovation networks. They outsource knowledge needed to complement their internally generated knowledge; and they license their technology to enhance the rents from innovation.

A second reason for cautious optimism is that, for global firms, benefits from innovation offshoring are too important to forgo them. Innovation offshoring allows global firms to reduce the rising costs of R&D and to gain access to new sources of innovation. In addition, innovation offshoring helps global firms to hedge against failures of internal R&D projects or against slippage in capacity expansion.

Third, global firms are now able to move to an open innovation system because an increasing division of labor in innovation has given rise to global markets for technology (Arora, *et al* 2001). This has enhanced their capacity to engage in innovation offshoring. Global markets for technology imply that a firm's competitive success critically depends on its ability to monitor and quickly seize external sources of knowledge (e.g., Iansiti, 1997). Global firms now must supplement the in-house creation of new knowledge and capabilities with basic or generic technologies developed elsewhere.

[17] On average, a new product generation is introduced every 9 months, and for some products the cycle can be as short as six months, almost as short as for fashion-intensive garments.

And fourth, global firms need innovation offshoring to improve their access to a limited global pool of knowledge workers. The shift to knowledge-intensive industries has increased the importance and scarcity of well-trained knowledge workers. At the same time, aging populations are reducing the available working populations in Europe, Japan and the US. Aging is also expected to become a serious challenge after 2010 for Asia's leading exporting countries (with the exception of India). This implies that, over the next decade or so, global firms will find it increasingly difficult to attract--and retain--enough qualified workers, especially scientists and engineers.

Hence, competing for scarce global talent has become a major strategic concern for many hi-tech companies. Global sourcing for knowledge workers now is as important as global manufacturing and supply chain strategies. The goal is to diversify and optimize a company's human capital portfolio through aggressive recruitment in global labor markets.

In short, innovation offshoring through global innovation networks is likely to expand knowledge diffusion. This implies that deeper integration into global innovation networks may well act as a catalyst for accelerating the development and the diffusion of innovative capabilities, *provided* of course that adequate policies and firm strategies are in place to enhance local innovative capabilities.

3. Generic Policy Suggestions

Innovation offshoring poses new opportunities and challenges for 'upgrading-through- innovation' strategies that Asian firms may be ill-equipped to address on their own. Hence, host country policies must continue to cajole and assist these firms by signaling opportunities, reducing risks, engaging in R&D and providing critical "public goods." Liberalization and WTO regulations have reduced the scope for such policies. The challenge is to design new policies and institutions that help to reduce the "divergence between the private interests of the multinational company and the social interests of the host economy in terms of long-term technology development." (Lall and Urata, 2003: p. 4)

The key to success is to use integration into GINs to catalyze, not replace, domestic innovation efforts, and to monitor and to hold firms accountable for their use of incentives and subsidies. In other words, innovation offshoring can only produce sustainable long-term economic benefits for Asian countries, if policies exist to develop strong local companies that can act as countervailing forces to the accumulated strengths of global firms. This is in line with the findings of Lall's research. But for Asia to cope with the complex challenges and opportunities of innovation offshoring, new policies are required that are very different from earlier top-down 'command economy'- type industrial policies that were typical for the 'East Asian development model.'

Recent research on the offshoring of chip design to Asia demonstrates the importance of well-functioning product and factor markets (Ernst 2005a). Market failures per se may not necessarily prevent global firms from investing in R&D, especially if this generates windfall profits. The main concern appears to be a certain degree of transparency and predictability that allows for longer-term planning that is necessary for R&D. Host country policies can actually use idiosyncratic market characteristics to differentiate a particular location and to increase its attractiveness for foreign R&D.

For instance, differences in financial markets can lead to diverse approaches to investment finance (e.g., debt, equity or retained earnings) that will influence the volume and direction of investment in complementary R&D activities by local firms. In addition, the examples of Korea and China demonstrate that host country policies to define alternative standards (i.e., for 3G mobile communication systems or open source software), combined with the use of government procurement can be powerful tools in attracting foreign R&D.

In the final analysis, however, policies to attract R&D by global firms can only succeed if they fulfill two critical conditions: they need to balance effective protection of IPRs with incentives for knowledge diffusion to local firms; and they need to provide a sufficiently large pool of knowledge workers who possess the skills needed to benefit from innovation offshoring.

3.1. Policies on intellectual property rights

If Asian countries seek to attract more advanced foreign R&D projects, effective protection of intellectual property rights becomes as important as the development of their own IPR.

Well-defined enforceable patents reduce transaction costs, and thereby help increase the mobility of knowledge. In theory, smaller firms (for instance local Asian firms) are expected to draw the greatest benefits. It is assumed that a stronger IPR regime increases the returns from investments in technology development more substantially for smaller innovative start-up companies than for the larger integrated companies.

In reality, however, the market for patents displays important imperfections (e.g., Jaffe and Lerner, 2004). For instance, reaping the benefits of IPRs may be costly, and small firms may face greater difficulties than large corporations in patenting. Even more important is the so-called ‘anti-commons’ problem (Arora et al., 2001: 263 ff). It is unrealistic to assume that each patent is associated with one innovation only.[18]

Typically however, IPR protection is fragmented. The resulting constraints to innovation can be substantial. For instance, for the inventor, the cost of ‘inventing around’ blocking patents can be extremely high. And the higher these costs are, the weaker is the innovator’s bargaining power in the licensing negotiations. This raises two important, but very tricky policy questions: How should different contributors be rewarded? And who is likely to capture most benefits? While institutional arrangements for IPR protection matter, the outcome is primarily determined by bargaining power. This indicates how difficult decisions are for Asian governments to find the level of IPR protection that balances the interests of global and local companies.

It is important to emphasize that the protection of IPR needs to be complemented with policies that foster the exchange of knowledge embodied in these IPRs. An important challenge for public policy is to establish a legal framework and a set of regulations that can facilitate the exchange of IPRs. A second equally important task would be to assign IPRs to the results of research that the government funds. One policy

[18] In the IT industry this is a serious problem, as innovation is systemic and cumulative, requiring many different pieces of knowledge, some of which may be patented and owned by companies with conflicting interests.

initiative that has attracted considerable attention from governments elsewhere is the Bayh–Dole Act of 1980 in the United States, which provided a framework for the encouragement of patenting and licensing of publicly funded R&D results by universities.

But within the United States, the effects and desirability of the Bayh–Dole Act remain controversial (Mowery et al., 2004). It is necessary to explore under what conditions the US approach to university-industry linkages can serve as a useful framework for policy elsewhere.

Unfortunately, very little scholarly research is available to guide policy debates on this important issue. Research on the role of universities in industrial innovation has focused on the United States, Japan and major European economies (e.g., Branscomb et al. 1999**)**. While there are a few pioneering studies on national innovation systems in Asian countries like Korea, Taiwan, China and Malaysia (e.g. Kim, 1997; Chi-Ming Hou and San Gee, 1997; Naughton and Segal, 2002; Rasiah, 1995), the role of university–industry linkages has not been at the centre of analysis. Most importantly, there is no systematic cross-national comparative research on the diverse development trajectories of developing countries' higher education systems and the diverse array of university–industry linkages (Ernst and Mowery, 2004).

3.2. Policies on education and skill development

Finally, an important yardstick for policies to attract foreign R&D is the supply of well-educated and experienced technicians, engineers, managers and scientists at a cost that is substantially lower than their cost at the home country locations of global firms. This requires incessant efforts on a massive scale to continuously upgrade existing skills and capabilities.

The lack of depth and horizontal mobility in the labor markets that is typical of most Asian countries increases the risk of individual investment in specialized skills. This explains why in many of these countries mismatches between the supply and the demand of specialized skills persist. To reduce these mismatches requires well thought-out policies.

A recent study on Malaysia's electronics industry (Ernst, 2004) shows that policy-makers and industry executives realize the need for new policies that address the following objectives (Ernst, 2004):

- re-skill and re-train production workers, technicians, and engineers;
- expose science and engineering students to best-practice methodologies and tools and adjust curricula development to evolving labor market needs;
- produce graduates, especially for electrical and electronics engineering, information technology, communication technology and circuit design who are able to combine hardware, software, and application knowledge;
- produce experienced managers, especially for strategic marketing, upgrading management, and management of international linkages;

- provide incentives for entrepreneurs that combine street-wise commercial and financial instincts with analytic capacity for strategic decision-making
- develop a cadre of experienced and industry-savvy administrators who are willing to stick out their necks and to do more than just follow the rules (this of course requires some incentive alignment);
- align incentives for university professors and academics that encourage close interaction with private sector (company internships and sabbaticals);
- encourage dense interactions with expatriate nationals who are based in the United States, Australia and Europe, or elsewhere in Asia; and
- bring in at short notice specialized experts from overseas who can help bridge existing knowledge gaps and who can catalyze necessary changes in organization and procedures required to develop these capabilities locally.

The latter two policy objectives are critical for policies to upgrade Asia's pool of knowledge workers. As global markets for knowledge workers evolve, such policies of leveraging international knowledge communities are also becoming more feasible.[19] This provides Asian countries with invaluable knowledge on global market and technology trends in a way that addresses the needs of domestic firms much better than formal linkages with global firms (Ernst, 2007g).

There are of course no one-best optimum formulas for such policies. Their instruments and institutions need to differ from sector to sector, in scope, in kind, and in impact, as documented in Mowery and Nelson (1999: 377).[20]

Policies also need to differ across countries. A critical prerequisite to find out more about such policy variations is the construction of relevant country classifications. But most such classifications remain problematic.[21] Drawing on Lall (1990), Ernst, Mytelka and Ganiatsos (1998), and Ernst and O'Connor (1989), it is possible to suggest a broader country classification scheme that focuses on the following criteria:

[19] In the electronics industry, for instance, these informal social networks link developing countries with the world's centers of information and communication technology (encompassing Silicon Valley and other centers of excellence in less well known places like Helsinki, Kista/Stockholm, Grenoble, Munich, Tsukuba, Tel Aviv, etc).

[20] Ernst (2005 a) provides a case study of chip design that highlights characteristic features of global design networks, and the resultant specific implications for the development of local innovative capabilities. Future research needs to conduct similar case studies for sectors that are of particular importance for developing countries, such as textiles, footwear, food processing, chemicals, pharmaceuticals, transportation equipment, mechanical engineering, as well as software and information technology services. For each of these sectors, there are likely to be substantial differences in host country policy responses to innovation offshoring.

[21] For instance, the World Bank's research on strategic approaches to science and technology in development uses the RAND Corporation's matrix of science and technology capacity in the developing world that distinguishes three categories: 24 "scientifically proficient" countries, 24 "scientifically developing" countries, and 80 "scientifically lagging" countries (Appendix 2, in Watson, Crawford and Farley, 2003).

- the size and structure of markets and the relative focus on internal versus external markets;
- production structures, including industry structure and firm size, extent of inter-industry linkages, and “core industries”;
- degree and form of reliance on foreign technologies;
- role of the state in industrial and technological development;
- state of development of indigenous scientific, technological and innovative capabilities;
- peculiar characteristics of economic institutions (i.e., labor and financial markets and education systems); and
- social, cultural and political factors that shape national, regional and sector-specific innovation systems.

Future research needs to examine what are realistic options for ‘upgrading-through-innovation’ strategies in different groupings of Asian countries, and how each of these policies can maximize benefits from participating in global innovation networks. For instance, Ernst (2005d) introduces a taxonomy of four strategies (i.e. “catching-up”, “fast-follower”, “technology diversification”, and “technology leader”) and explores what capabilities local companies need to master to implement each of these four different strategies. Drawing on this taxonomy, the UN Millennium Project Report on Science, Technology and Innovation (UN Millennium Project, 2005: 127) recommends “technological diversification” as a particularly attractive policy to upgrade industries through innovation.

Conclusions

This paper demonstrates that Lall’s framework for analyzing Asian pathways to development remains valid, once globalization extends beyond markets for goods and finance into markets for technology and knowledge workers. As offshoring has moved beyond industrial manufacturing into services, engineering and research, new opportunities and challenges arise for Asian economies.

We have explored how innovation offshoring is driven by fundamental changes in the economics of innovation and the resultant adjustments in corporate strategies and government policies. To examine what this implies for Asia’s ‘upgrading-through-innovation’ strategies, I have introduced a concept of ‘industrial upgrading’ that links specialization with firm-level and industry-level upgrading and high integration into global networks. This concept allows us to identify conditions under which Asian countries could reap the benefits of innovation offshoring.

Our analysis shows that Lall was right to emphasize a divergence between the private interests of the multinational company and the social interests of the host economy in terms of long-term technology development. And his plea for industrial policy is even more valid today, as the stakes and risks have become much higher, as countries seek to move beyond the ‘global factory’ model to ‘upgrading-through-innovation’ strategies.

Lall was also right to emphasize that, the more a country moves up the industrial ladder, the more important are advanced capabilities and innovation. The paper demonstrates however that there is room for cautious optimism that a host country’s progressive integration into global innovation networks could facilitate its efforts to push ahead with industrial upgrading.

Most importantly, we have seen that, in line with Lall's research, the key to success is to generate a virtuous circle of institutions and firm-level capabilities.

Finally, the paper also supports Lall's argument that there are no "one-best way"-solutions. Instead, policies and strategies need to be continuously adjusted to the vagaries of business cycles and, even more importantly, to the structural transformations of global markets and technology.

References

Archibugi, D. and J. Michie (1995) 'The globalisation of technology: a new taxonomy', *Cambridge Journal of Economics*, 19:1.

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

Borrus, M., D. Ernst and S. Haggard (eds) (2000) *International Production Networks in Asia: Rivalry or Riches?* London: Routledge.

Branscomb, L.M., F. Kodama and R.L. Florida (1999) *Industrialising Knowledge: University-Industry Linkages in Japan and the United States*. Cambridge MA: MIT Press.

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

Chang, Yuan-Chieh, Chin-Tay Shih and Yi-Ling Wei, 2006. "Hooking up local and national innovation networks: a study of foreign-affiliated R&D centers in Taiwan", presented at international workshop "Greater China's Innovative capacities: Progress and Challenges", co-sponsored by SPRIE/Stanford University and CISTP/ Tsinghua University, May 20-21, 2006, in Beijing, China.

Chen, Shin-Horng, 2002. "Global Production Networks and Information Technology: the Case of Taiwan", *Industry and Innovation*, special issue "Global Production Networks" (Ernst, D. and Linsu Kim, eds.), volume 9, no. 3: 249-265.

Chen, Shin-Horng, 2006. "The National Innovation System and Global R&D Strategies: The Case of Taiwan", paper prepared for conference "R&D Interplay in Northeast Asia: Global Corporate Strategy and Host Countries' National Innovation System", Seoul, February 24.

Chen, Tain-jy, 2004. "The Challenges of the Knowledge-Based Economy", in: Chen, Tain-jy and Joseph S. Lee (eds), *The New Knowledge Economy of Taiwan*, Cheltenham: Edward Elgar.

CHI/MIT, 2003. *2003 Innovation Scores Survey*. Available at www.CHI.com.

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

Department of Commerce, 2004, *Survey of US Direct Investment Abroad*, Bureau of Economic Analysis, Washington, D.C.

Dunning, J.H. (1998) 'Globalization, technology and space', in Chandler, A.D., P. Hagstrom and O. Solvell (eds), *The Dynamic Firm: The Role of Technology, Strategy, Organisation, and Regions*. Oxford: Oxford University Press.

Ernst, D. (1994) *What are the Limits to the Korean Model? The Korean Electronics Industry Under Pressure*. Berkeley, CA: The Berkeley Roundtable on the International Economy (BRIE)

Ernst, D. (1997) ‘From partial to systemic globalisation. International production networks in the electronics industry’. Report to Sloan Foundation, published as *The Data Storage Industry Globalisation Project Report 97-02*, Graduate School of International Relations and Pacific Studies, University of California at San Diego.

Ernst, D., 2001a. “Small Firms Competing in Globalized High Tech Industries: The Co-Evolution of Domestic and International Knowledge Linkages in Taiwan’s Computer Industry”, in: Guerrieri, P., S. Iammarino, and C. Pietrobelli (eds.), *The Global Challenge to Industrial Districts. Small and Medium-Sized Enterprises in Italy and Taiwan*, Aldershot: Edward Elgar.

Ernst, D. (2001b) ‘Responses to the Crisis: Constraints to Rapid Trade Adjustment in East Asia’s Electronics Industry’, chapter 12, in: Chang, H.J., Palma, G. and Whittaker, D.H. (Eds.): *Financial Liberalization and the Asian Crisis*, Palgrave, Houndmills, Basingstoke.

Ernst, D. (2002a), ‘Global Production Networks and the Changing Geography of Innovation Systems. Implications for Developing Countries’, *Economics of Innovation and New Technologies* XI(6): 497–523.

Ernst, D. (2002b) ‘The economics of electronics industry: competitive dynamics and industrial organisation’, in William Lazonick (ed.), *The International Encyclopedia of Business and Management* (IEBM), *Handbook of Economics*, London: International Thomson Business Press.

Ernst, D. (2004) ‘Global production networks in East Asia’s electronics industry and upgrading perspectives in Malaysia’, in: S. Yusuf, M.A. Altaf and K. Nabeshima (eds), *Global Production Networking and Technological Change in East Asia*, Washington DC: World Bank and Oxford University Press.

Ernst, Dieter (2005a) ‘Complexity and internationalisation of innovation: why is chip design moving to Asia?,’ *International Journal of Innovation Management* [special issue in honour of Keith Pavitt], 9(1): 47–73.

Ernst, D. (2005b) ‘Limits to modularity: reflections on recent developments in chip design’, *Industry and Innovation*, 12(3): 303–335.

Ernst, D. (2005c) ‘The New mobility of knowledge: digital information systems and global flagship networks’, in: R. Latham and S. Sassen (eds), *Digital Formations. IT and New Architectures in the Global Realm*, Princeton and Oxford: Princeton University Press for the US Social Science Research Council.

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; 29(1/2): 6–20.

Ernst, D. (2006a), *Innovation Offshoring: Asia’s Emerging Role in Global Innovation Networks*, a special report prepared for the East-West Center and the U.S.-Asia-Pacific Council, East-West center, Honolulu, July

Ernst, D. (2006b) “Searching for a New Role in East Asian Regionalization—Japanese Production Networks in the Electronics Industry.” In Katzenstein, P., J.

Katzenstein, and T. Shiraishi, (eds.) *Remaking East Asia: Beyond Americanization and Japanization.* Cornell: Cornell University Press Paperbacks.

Ernst, D. (2007a), “Innovation Offshoring - Root Causes of Asia’s Rise and Policy Implications”, chapter 3 in : Palacios, Juan J. (Ed.), 2007, *Multinational Corporations and the Emerging Network Economy in the Pacific Rim*. London: Routledge. Co-published with the Pacific Trade and Development Conference (PAFTAD)

Ernst, D. (2007b) ‘Developing Innovative Capabilities in Chip Design. Insights from the US and Greater China’, Honolulu: manuscript, East-West Center.

Ernst, D. (2007c), *Taiwan’s Electronic Design Capabilities - Achievements and Challenges*, manuscript, East-West Center.

Ernst, D., 2007d, “Innovation in the Global Knowledge Economy”, Honolulu: manuscript, East-West Center

Ernst, D. (2007e) ‘Upgrading through innovation in a small network economy: insights from Taiwan’s IT industry’, paper prepared for 2007 Atlanta Conference on Science, Technology and Innovation Policy, Georgia Institute of Technology, October 18-20

Ernst, D. (2007g), ‘Can Chinese IT firms develop innovative capabilities within global knowledge networks?’. chapter 8 in: *China's Quest for Independent Innovation* (Marguerite Gong Hancock, Henry S. Rowen, and William F. Miller, editors), Shorenstein Asia Pacific Research Center and Brookings Institution Press

Ernst, Dieter and David O'Connor, 1989, Technology and Global Competition. The Challenge for Newly Industrialising Economies, OECD Development Centre Studies, Paris, 149 pages

Ernst, D., L. Mytelka and T. Ganiatsos (1998) ‘Export performance and technological capabilities: A conceptual framework’, in: Ernst, D.; T. Ganiatsos and L. Mytelka (eds), *Technological Capabilities and Export Success: Lessons from East Asia*, London: Routledge Press.

Ernst, D. and Linsu Kim (2002) ‘Global production networks, knowledge diffusion and local capability formation’, *Research Policy*, special issue in honour of Richard Nelson and Sydney Winter, 31(8/9): 1417–1429.

Ernst, D. and D. Mowery (2004) ‘University–industry linkages in the Pacific Rim: Public policy issues’, manuscript, February, Honolulu: East-West Center.

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 Publishing.

Feldman, M.P. (1999) ‘The new economics of innovation, spillovers and agglomeration: a review of empirical studies’, *Economics of Innovation and New Technology* 8: 5–25.

Freeman, C., 1987. *Technology Policy and Economic Performance: Lessons from Japan,* London, Pinter Publishers

Freeman, C., 1997. "Innovation Systems: City-State, National, Continental and Sub-National", mimeo, Science Policy Research Unit (SPRU), University of Sussex, December.

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

Hou, Chi-Ming and San Gee, 1993. "National Systems Supporting Technical Advance in Industry: The Case of Taiwan", in Richard R. Nelson, (ed.), *National Innovation Systems. A Comparative Analysis,* Oxford: Oxford University Press.

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

IBM (2006), *Expanding the Innovation Horizon. The Global CEO Study 2006*, IBM Business Consulting Services, Somers, NY 10589

Jaffe, A.B. and J. Lerner (2004), *Innovation and its Discontents*, Princeton University Press, Pinceton and Oxford

Jaffe, A.B., M. Trajtenberg and M.S. Fogarty (2000) 'Knowledge spillovers and patent citations: Evidence from a survey of inventors', *American Economic Review,* 90, AEA Papers and Proceedings, 215–218.

Kim, Linsu (1997) *Imitation to Innovation: The Dynamics of Korea's Technological Learning*, Boston: Harvard Business School Press.

Kim, Youngsoo (2000), "Technological Capabilities and the Samsung Electronics Network", in Borrus, M., D. Ernst and S. Haggard, eds. *International Production Networks in Asia: Rivalry or Riches?* London: Routledge

Kogut, B. and U. Zander (1993), 'Knowledge of the firm and the evolutionary theory of the multinational corporation', *Journal of International Business Studies*, 24 (4): 625.

Lall, S., 1990, *Building Industrial Competitiveness in Developing Countries,* OECD Development Centre, Paris

Lall, S., 2000, "Technological Change and Industrialization in the Asian Newly Industrializing Economies: Achievements and Challenges", chapter 2 in: Linsu Kim and Richard R. Nelson (eds), *Technology, Learning and Innovation. Experience of Newly Industrializing Economies,* Cambridge University Press

Lall, S., 2003, "Foreign Direct Investment, Technology Development and Competitiveness: Issues and Evidence", chapter 2 in: S. Lall and S. Urata (eds), *Competitiveness, FDI and Technological Activity in East Asia*, published in association with the World Bank, Edward Elgar, Cheltenham, UK
London: Pinter Publishers.

Lall, S and S. Urata, 2003, "Introduction and Overview", in: S. Lall and S. Urata (eds), *Competitiveness, FDI and Technological Activity in East Asia*, published in association with the World Bank, Edward Elgar, Cheltenham, UK

Lundvall, B.A., (ed.), 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, Pinter Publishers, London.

Mowery, D.C. and R.R. Nelson (eds.), 1999, Sources of Industrial Leadership. Studies in Seven Industries, pp. 79- 132, Cambridge University Press, Cambridge

Mowery, D., R.R. Nelson, B.N. Sampat and A.A. Ziedonies (2004) *'Ivory Tower' and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act in the United States*, Stanford,CA: Stanford University Press.

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

National Science Board, 2006. *Science and Engineering Indicators 2006*, volume I, Arlington, VA: National Science Foundation.

Naughton, B and A. Segal (2002) 'Technology development in the new millennium: China in search of a workable model', in William Keller and Richard Samuels (eds), *Crisis and Innovation: Asian Technology after the Millenium*, Cambridge: Cambridge University Press

Nelson, R. R. (ed.), 1993. *National Innovation Systems: A Comparative Analysis*, Oxford: Oxford University Press.

Ozawa, T. (2000) 'The "Flying-Geese Paradigm": Toward a Co-evolutionary Theory of MNC-Assisted Growth', in Fatemi, K. (Ed.): *The New World Order: Internationalism, Regionalism and the Multinational Corporations*, Pergamon, Amsterdam and New York.

Patel, P. and K. Pavitt (1991) 'Large firms in the production of the world's technology: An important case of non-globalisation', *Journal of International Business Studies*, 22(1): 1–21.

Porter,M. and Ø. Sølvell (1998) 'The role of geography in the process of innovation and the sustainable competitive advantage of firms', in: Chandler et al (eds), *The Dynamic Firm. The Role of Technology, Strategy, Organisation, and Regions*, Oxford: Oxford University Press.

Rasiah, R. (1995) Foreign Capital and Industrialisation in Malaysia, Basingstoke: Macmillan.

Sachwald, F., ed. (2001), *Going Multinational. The Korean Experience of Direct Investment*, Routledge: London and New York

UN Millenium Project 2005, *Innovation: Applying Knowledge in Development. Task Force on Science, Technology and Innovation*, United Nations Development Programme and Earthscan, New York and London

UNCTAD (2005b) *UNCTAD Survey on the Internationalisation of R&D. Occasional Note*, UNCTAD/WEB/ITE/IIA/2005/12, 12 December

Venables, Anthony J., 2006. "Shifts in Economic Geography and their Causes", paper prepared for 2006 Jackson Hole Symposium, August 25.

Vernon, R. (1966) 'International Investment and International Trade in the Product Cycle', *The Quarterly Journal of Economics*, Vol. 80, No. 2, pp. 190-207.

Watson, R.M. and S. Farley, 2003, *Strategic Approaches to Science and Technology in Development*, World Bank Policy Research Paper 3026, April