Innovation offshoring and outsourcing: what are the implications for industrial policy?

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Abstract: This paper examines how innovation offshoring through global innovation networks affects Industrial Upgrading (IU) policies in Asia's electronics industry. I argue that developing countries cannot build their innovative capabilities by solely relying on their national innovation systems. For quite some time, these countries will have to draw primarily on foreign sources of knowledge as a catalyst for learning and capability formation. The paper discusses generic policy issues that host countries need to address to maximise the benefits of innovation offshoring. To leverage the potential benefits from global network integration, host countries must have in place vigorous policies to reduce the potentially high costs that may result from 'brain drain' (both domestic and international) when Trans-National Corporations (TNCs) are crowding out the local market for scarce skills, from the acquisition by TNCs of innovative local companies and from a potential deterrence effect of TNC labs on local R&D. I emphasise the critical importance of policies to develop strong local companies that can act as countervailing forces.

Keywords: innovation offshoring; Global Innovation Network; GIN; Trans-National Corporations; TNCs; Industrial Upgrading; IU; industrial policy; brain drain; national innovation systems; innovation clusters.

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1 Introduction

To reap the benefits of innovation offshoring, developing countries must broaden their domestic knowledge base and generate specialist capabilities. This cannot be left to market forces alone. Markets are notoriously weak in generating knowledge and capabilities, as both are subject to market failures externalities: investments in knowledge and innovation are typically characterised by a gap between private and social rates of return (Arrow, 1962). Reducing this gap requires corrective policy interventions that provide incentives, as well as the necessary infrastructure, support services and human resources.

In addition, rapid technological change (such as Information and Communications Technology (ICT)) and globalisation both accelerate the pace of change in markets and technology and increase uncertainty and the volatility of market structures, industrial organisation and firm behaviour (Ernst, 2005a). Hence, there is now a much greater need for public policy that goes well beyond traditional view on correcting market failures. This does not imply a return to the status quo ante of the command-style developmental state. The challenge is to redefine the role of government intervention (Rodrik, 2000). The real question, then, is no longer whether national policies and institutions can make a difference. Instead, it is what kind of policies and institutions will prove best at unlocking new sources of economic growth through participation in Global Innovation Networks (GINs).

The concept of Industrial Upgrading (IU) can serve as a focusing device (Ernst, 2001) to identify an appropriate long-term development strategy. Such a strategy must focus on improvements in specialisation, productivity and linkages (as defined by Hirschman (1958, chapter 6)), all of which necessitate a broad base of skills and capabilities. All these elements are essential prerequisites for improving a country's capacity to raise the long-term capital necessary for facility investment, R&D and human resource development. The IU concept ties the four elements together in a cohesive framework to serve as a focusing device for unlocking new sources of economic growth.[1] Critical prerequisites for successful upgrading are a sufficiently large pool of specialist and re-trainable skills, a strong domestic knowledge base, forms of corporate governance that facilitate innovation, sophisticated information management, and strong international knowledge linkages.

This paper examines the implications for IU policies that result from the analysis of innovation offshoring in Asia's electronics industry in GINs. The discussion focuses on three generic policy issues that host countries need to address to maximise the benefits from the internationalisation of innovation: (1) What changes in IU strategies are required as Asia emerges as an important location for GINs that are being grafted on to existing GPNs? (2) What are the implications for policies that seek to attract and expand R&D by Trans-National Corporations (TNCs) in order to become better connected to GINs? (3) What policies can host countries use to enable local firms to leverage participation in such networks to develop their own innovative capabilities?

Section 1 introduces the concept of IU that emphasises the importance of international forward and backward linkages. Section 2 examines, from a developing country's policy perspective, what benefits integration into GINs may provide. Section 3 explores the rationale for policies to attract and expand R&D by TNCs. Section 4 looks at policy issues related to Intellectual Property Rights (IPR), while Section 5 discusses the implications for policies on education and skill development. Finally, Section 6 examines

what policies developing countries can use to enable local firms to leverage participation in GINs to develop their own innovative capabilities. Section 7 summarises key findings and highlights policy suggestions and suggestions for future research.

1.1 Firm-level upgrading and industry-level linkages

This paper focuses on two aspects of IU found in the literature: 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. Without the latter, the firm-level upgrading will soon reach its limits.[2] Two additional features that distinguish this concept of IU are emphasised. Firstly, firm behaviour is a key dimension, allowing for a co-evolution of industry structure and firm behaviour in response to the actions of key participants and also to the policy environment. And secondly, a broad definition of innovation is used that allows the discussion to move beyond a narrow focus on R&D and patenting.[3] There is now a widespread consensus that a broad definition of innovation efforts is needed, which includes engineering, technology purchases, expenditures on licensing and consulting services, and technology search, as well as the accumulation of tacit knowledge required to absorb imported technology (Nelson, 1990). The broader focus is necessary to capture the proliferation of knowledge-intensive professional services made possible by ICT.

The stylised framework of IU used is designed to explain how specialisation affects market structure and upgrading potential. The framework also highlights the dynamics of IU, and the conditions that make it possible to move from a vicious to a virtuous circle of IU. Most importantly, a definition of IU is used that emphasises the importance of international linkages.

Specialisation is an important indicator of the degree of IU that a country has achieved. Specialisation patterns reflect differences in product and production characteristics (homogeneous versus differentiated products), and in production characteristics (mass production versus flexible production) (see Table 1). The differences, in turn, are based on two criteria – the complexity of technology and the peculiar characteristics of demand (uncertainty). Differences in product and production characteristics also result in different market structures and account for different upgrading potential, i.e. augmenting the technological knowledge base and deepening Hirschman-type linkages.

The purpose of this exercise becomes clear when the last row of the specialisation matrix is seen. While homogeneous products have only a limited upgrading potential, in terms of technological learning requirements and linkages, the opposite is true for differentiated products. Similar distinctions can be made for production processes, with flexible production linked to premium pricing and significant profit margins that give rise to substantial upgrading potential. The downside to flexible production, of course, is the substantially higher upfront preparatory efforts that are necessary for successful entry. It is important to emphasise that causality works both ways – while a narrow specialisation on commodities does not provide sufficient pressure to broaden the domestic knowledge base and to develop forward and backward linkages, it is also true that necessary improvements in specialisation are constrained by a narrow domestic knowledge base and limited linkages, giving rise to a vicious cycle.

As national production and innovation systems are increasingly integrated into complex global production network arrangements, it is no longer possible to assume that

IU ends at the national border, and that it occurs only if improved specialisation generates pressures to create dense forward and backward linkages within the district or the national economy. A closed economy assumption is unrealistic, as globalisation and Information Technology (IT) have drastically increased the international mobility of trade, investment and even knowledge (Ernst, 2003). This increases the scope for cross-border forward and backward linkages, in the same way that improved specialisation generates pressures to create dense forward and backward linkages within the economy (Ernst, 2002).

Table 1 Specialisation – upgrading matrix

Variables	*Complexity of technology/uncertainty of demand*	
	Low specialisation	*High specialisation*
Product characteristics	*Homogeneous (commodities)* • Mature technology • Established design • Easy to replicate • Predictable changes in demand and technology • Limited interactions with customers	*Differentiated* • New technology • Fluid design • Difficult to replicate • Unpredictable changes • Close interaction with customers
Production characteristics	*Mass production* • Economies of scale & scope	*Flexible specialisation* • Speed of response
Market structure	• Low entry barriers • Price competition • Limited profit margin capabilities: • Periodic overcapacity & price wars • Deflationary pricing pressures	• High entry barriers • Premium pricing • Significant profit margin capabilities
Upgrading potential	• Limited technological learning requirements • Limited pressure to develop forward & backward linkages	• Substantial pressure to broaden & deepen local knowledge base • Ditto for linkages

Source: Author

Equally important, most countries are constrained by a narrow domestic knowledge base and limited linkages. Both these constraints are particularly relevant for small, developing economies, because one of their primary features is a narrow and incomplete set of domestic linkages (Ernst et al., 1998a; Lall, 2000). The result is an inverted production pyramid: a growing final product sector rests on a weak and much smaller domestic base of mostly inefficient support industries. Rapid growth in the final products sector necessitates considerable imports of intermediates and production equipment. In addition, highly heterogeneous economic structures constrain agglomeration economies; weak and unstable economic institutions obstruct learning efficiency; and a high vulnerability to volatile global currency and financial markets constrains patent capital that is necessary for the development of a broad domestic knowledge base. As a

result of this vicious circle, limited sharing and pooling of resources and knowledge occurs within the country, and often even within the export-oriented cluster. This implies that this model of IU needs to integrate international knowledge linkages. To compensate for their narrow domestic knowledge base and limited linkages, Asian developing economies have to rely on foreign sources of knowledge to catalyse domestic capability formation. International linkages thus need to prepare the way for an upgrading of East Asia's electronics industries.

2 Pros and cons of integration into GINs

Internationalisation of innovation is expanding into locations outside the industrial heartlands of the Organisation for Economic Co-operation and Development (OECD). As the organisational and geographical mobility of innovation increases, countries and regions around the globe are competing to attract and expand R&D by TNCs, and to be integrated into their GINs. An important implication is that as countries progress in their economic development, they will increasingly rely on knowledge exchange through these networks. This is especially the case for developing countries. It is thus time to acknowledge that a nation's innovation system contains a critically important international dimension (Ernst, 2002). Unfortunately, most of the literature on innovation and the firm "... has not generally embraced an international dimension and, as a result, our understanding of the way resources are organized and distributed across national boundaries has been constricted" (Dunning, 1998, p.291).

As more and more countries become connected to these networks, it will increase the pressure on other countries to attract R&D by TNCs in order to avoid being sidelined in an increasingly interconnected global innovation system. Hence, integration into GINs seems to emerge as an increasingly important determinant of future prospects for economic development. But there are also concerns that network integration may be a poisoned chalice. It is feared that at best it may only produce short-term benefits, and that it may not provide the means for upgrading the host country's industry to higher value-added and more knowledge-intensive activities.

Unfortunately, research on these issues is still at very early stage – there is little robust data, and "the implications suggested by the few studies tend to be postulated hypotheses" (Reddy, 2000, p.40). In addition, obtaining data on the offshoring of R&D is becoming more difficult, as TNCs are loath to disclose sensitive information that could affect their stock market quotation. However, the literature does provide theoretical as well as empirical reasons to argue that from a developing country's policy perspective, integration into GINs may provide substantial benefits (Ernst et al., 1998b; Lall, 2000). Mathews (2002, p.VIII), for instance, argues that much of the success of Asian export-led industrialisation was due to international knowledge sourcing – Asian countries were able to overcome their initial disadvantages through strategies "... to leverage knowledge and technologies from their more advanced competitors ... (that) utilize the existing and latent inter-firm connections of the global economy". In addition, Ernst (2002) argues that a limited domestic knowledge base implies that developing countries must access and use external sources of knowledge.

It is possible to push that argument one step further. In a case study of Malaysia's electronics industry, Ernst (2004) demonstrates that attracting foreign R&D may not only compensate for initial weaknesses of the domestic knowledge base. Such international

knowledge sourcing may also facilitate the adjustment of business organisation and strategy to abrupt changes in technology and markets. Under certain conditions, attracting R&D by TNCs may also catalyse the development and the diffusion of innovative capabilities ahead of what the market would provide.

3 Rationale for policies to attract and expand R&D by TNCs

All of this implies that developing countries cannot build their innovative capabilities by relying solely on their national innovation systems and by developing localised innovation clusters. For quite some time, these countries will have to draw primarily on foreign sources of knowledge as the main vehicle of learning and capability formation. But in order to reap the potential benefits from network integration, host countries must have in place vigorous policies to reduce the potentially high costs that may result from brain drain (both domestic and international) when TNCs are crowding out the local market for scarce skills. Other sources of network integration costs include a possible deterrent effect on local R&D by TNC labs, the acquisition by TNCs of innovative local companies and the disproportionately high benefits that may accrue to a foreign parent company. In other words, if no policies exist to develop strong local companies that can act as countervailing forces, integration into GINs is unlikely to produce sustainable, long-term, economic benefits.

Evans (1995) provides a useful taxonomy of the following four roles of public policy in industrial development: (1) the 'custodian' role in which the state regulates the market, generally privileging the policing function over promotional policies, (2) the 'demiurge' in which the state plays an entrepreneurial role, not just to provide public goods but out of a presumption that private capital is not adequate to attain the whole gamut of production, (3) 'midwifery' where instead of substituting for the private sector, the state tries to shape it out of a belief that the capacity of the private sector is malleable and (4) 'husbandry' in which the state takes a long-term view by recognising that even if it successfully induces private groups to tackle promising sectors in its role of midwife, this is only just the beginning of a long process of IU.

The internationalisation of innovation poses new opportunities and challenges that local firms may be ill-equipped to address on their own. Hence, host-country policies must continue to cajole and assist these firms by signalling opportunities, reducing risks, engaging in R&D and providing critical public goods. Due to liberalisation and WTO regulations, there is limited scope for the custodian and the demiurge role of public policy. The challenge is to design policies and institutions that combine midwifery and husbandry. This implies that the key to success is to use integration into GINs to catalyse, not replace, domestic innovation efforts, and to monitor and to hold firms accountable for their use of incentives and subsidies. Once the initial catching-up phase is over, equal treatment should be provided to domestic and foreign firms, subject to one important exception: the promotion of risk-taking and innovative smaller domestic companies, as demonstrated successfully in Taiwan Province of China (Ernst, 2000).

While a consensus was reached in the literature that the pursue of liberal policies in trade and investment flows has been an important root cause of the internationalisation of innovation, there is also a growing consensus that liberalisation of trade and investment flows is not identical to a retreat of the state (Rodrik, 1999). Developing countries need to complement liberalisation with proactive and sophisticated industrial, innovation and

investment policies. Without such policies, liberalisation may well produce negative results: instead of improving efficiency and growth, liberalisation may increase a country's vulnerability to highly volatile international finance and currency markets; it may expose host countries to aggressive TNC strategies of exploiting the local talent pool, giving little in return; and it may obstruct attempts to strengthen local capabilities and innovation. As the example of small Nordic countries demonstrates, the scope for proactive technology and industrial policies in a liberal ownership regime is far greater than commonly assumed. Taiwan Province of China, Singapore and developments in the Republic of Korea also illustrate that a variety of approaches to such policies is possible, including hybrid combinations. The choice is much larger than normally assumed.

In addition, 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. Opportunities result from the increasingly fine-grained division of innovative labour, and the emerging global markets for technology and knowledge workers (Ernst, 2005b). In principle, this creates new opportunities for the international sourcing of key component technologies and scarce specialist skills. On the low end, this may enable local suppliers to produce specialist innovation services such as 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).

Massive challenges, however, must be overcome before host countries can exploit these opportunities. Such challenges result from the demanding requirements that locations need to fulfil in order to qualify for R&D investments by TNCs. For instance, TNCs routinely expect access to high-quality but low-cost infrastructure and information and communication systems. They 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.

Research on chip design also demonstrates the importance of well-functioning product and factor markets that are shaped by diverse host-country policies and regulations (Ernst, 2005c). Market failures per se may not necessarily prevent TNCs from investing in R&D, especially if this generates windfall profits. The main concern of TNCs appears to be a certain degree of transparency and predictability that allows for the longer-term planning that is necessary for R&D. Host-country policies can actually use idiosyncratic market characteristics to differentiate a particular location and 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 the Republic 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 R&D by TNCs.

In the final analysis, however, policies to attract R&D by TNCs can only succeed if they fulfil the following 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.

4 Policies on intellectual property rights

There is broad consensus that TNCs are unlikely to establish an R&D lab in a country that cannot guarantee effective IPR protection. There is a vast literature that demonstrates that a strong IPR regime is critical to encourage innovation (Granstrand, 1999; Teece, 2000). Well-defined enforceable patents reduce transaction costs and thereby help increase the mobility of knowledge. In theory, the distribution of benefits from IPR protection should encourage smaller firms (for instance, local host-country firms) relative to large incumbent market leaders. Smaller firms are expected to draw greater benefits than larger integrated companies from a stronger IPR regime.

In reality, the market for patents displays important imperfections (Arora et al., 2001, p.262). 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, e.g. when rational individuals collectively waste a given resource by underutilising it (Arora et al., 2001, p.263 ff). It is unrealistic to assume that each patent is associated with one innovation only. In the IT industry this is a serious problem, as innovative activities require highly complex knowledge. In complex technology systems, innovation is systemic and cumulative, requiring many different pieces of knowledge, some of which may be patented and owned by companies with conflicting interests. 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. In addition, the higher the cost, the weaker is the innovator's bargaining power in the licensing negotiations.

This raises two important but tricky policy questions: (1) How should different contributors be rewarded? (2) Who is likely to capture the most benefits? While institutional arrangements for IPR protection matter, the outcome is primarily determined by bargaining power. This indicates how difficult it is for host-country governments to find the level of IPR protection that balances the interests of TNCs and local companies.

An additional complicating factor for policy formulation is that the role of IPRs differs not only across industries, but also for different strategic groups of firms within an industry. For instance, research on semiconductors shows that large global industry leaders (such as Intel) patent for different reasons than do design houses (Hall and Ham, 1999). Industry leaders are primarily interested in leveraging a broad-based and impenetrable portfolio of patents to improve their bargaining position, especially in three areas: to avoid costly litigation, to increase revenue from IPRs and to expand market penetration in complementary segments. An example of the latter motivation is IBM's use of its broad patent portfolio to penetrate the high-end market for silicon foundry services. Fabless design houses, on the other hand, have two primary objectives when submitting patent applications: to establish rights in well-defined product niches and to raise funds from financial markets.

With progressive internationalisation of innovation, protection of IPRs needs to be complemented by policies that foster the exchange of knowledge embodied in these IPRs. One critically important aspect is the development of effective linkages between

universities and public research institutes on the one hand, and the R&D establishments of private business (Ernst and Mowery, 2004) on the other.

There is a widespread perception that the USA's leadership in industrial innovation owes much to the capacity of its higher education system to provide multiple and dense interlinkages between university research and innovation in enterprises. This explains why major developing nations have launched or are considering significant public policy initiatives to strengthen university–industry linkages, in many cases consciously modelling these efforts on the perceived success factors in the USA. Many of these initiatives seek to spur local economic development based on university research. This includes, for instance, the creation of science parks located near research university campuses, the support for business incubators and public seed-capital funds, and the organisation of other forms of bridging institutions that are believed to link universities to industrial innovation.

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 initiative that has attracted considerable attention from governments elsewhere is the 1980 Bayh–Dole Act in the USA, which provided a framework for the encouragement of patenting and licensing of publicly funded R&D results by universities. But within the USA, the effects and desirability of the Bayh–Dole Act remain controversial (Mowery et al., 2004). There are concerns that this approach may slow the diffusion of useful basic knowledge to the rest of society. While US universities have been important sources of knowledge and other key inputs for industrial innovation, much of this economic contribution has relied on channels other than patenting and licensing. Such broader university–industry linkages include knowledge exchange through publications, conference presentations and faculty consulting, as well as the movement of personnel between universities and industry.

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, 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 USA, Japan and major European economies (Branscomb et al., 1999). While there are a few pioneering studies on national innovation systems in Asian countries such as the Republic of Korea, Taiwan Province of China, China and Malaysia, 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.

Future policy-related research needs to address in particular the critically important international dimension of university–industry linkages. Specifically, such research needs to explore the following questions (Ernst and Mowery, 2004): What role are TNCs playing as collaborators with national universities in developing countries? What are the emerging patterns of internationalisation of university–industry linkages through integration into GINs? What new possibilities are emerging for the international exchange of scarce human resources? What role are international advisory boards playing in the reform of university–industry linkages? What new opportunities are emerging for the recruitment of foreign specialists as researchers and R&D managers? What are the prospects for a reversal of the international brain drain?

In light of these complex problems relating to IPR protection policies, it is not surprising to find that many developing countries have made only half-hearted efforts to develop strong IPR regimes. In the case of China, this raises an important puzzle: what explains the fact that China, despite its weak IPR regime, has been able to attract a substantial inflow of R&D investments by TNCs?

5 Policies on education and skill development

Arguably the most important yardstick for policies to attract R&D by TNCs is the supply of well-educated and experienced technicians, engineers, managers and scientists at a cost that is substantially lower than in the TNCs' home-country locations. As demonstrated in the case study on chip design, the relevant cost measure includes not just salary, but benefits, equipment, office space and other infrastructure. A recent study on Malaysia's electronics industry (Ernst, 2004) shows that this requires fundamental improvements in education systems to make sure that science and engineering students are exposed to the latest methodologies and tools, and to adjust curricula development to evolving labour market needs.

Policies to attract R&D by TNCs can only succeed if they are backed by incessant efforts on a massive scale to upgrade existing skills and capabilities. The lack of depth and horizontal mobility in the labour markets, which is typical of most developing countries, increases the risk of individual investment in specialist skills. This explains why in many countries mismatches between the supply of and the demand for specialist skills persist. To reduce these mismatches requires well-thought-out policies. In the case of Malaysia's electronics industry, policy-makers and industry executives realise the need for new policies that address the following objectives (Ernst, 2004):

- re-skill and retrain production workers, technicians and engineers
- produce graduates, especially for electrical and electronics engineering, IT, 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 streetwise commercial and financial instincts with analytic capacity for strategic decision-making
- develop a cadre of experienced and industry knowledgeable administrators who are willing 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 the private sector (company internships and sabbaticals)
- encourage dense interactions with expatriate nationals who are based in the USA, Australia and Europe, or elsewhere in Asia
- bring in, at short notice, specialist experts from overseas who can help bridge existing knowledge gaps and who can catalyse the necessary changes in organisation and procedures required to develop these capabilities locally.

The latter two policy objectives are critical for host-country human resource development policies. As global markets for knowledge workers evolve, such policies of leveraging international knowledge communities are becoming more feasible. In the electronics industry, for instance, these informal social networks link developing countries with the world's centres of ICT (encompassing Silicon Valley and other centres of excellence in less well-known places such as Helsinki, Kista/Stockholm, Grenoble, Munich, Tsukuba, Tel Aviv, etc.). This provides developing 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 TNCs. International knowledge communities also provide entrepreneurs and venture capitalists that can function in both worlds. This has created alternative and robust mechanisms of knowledge exchange across geographic borders and firm boundaries. Examples include Israel, Taiwan Province of China, Republic of Korea, India and China, as well as Mexico and Brazil.

Some of these policies to develop a broad-based pool of knowledge workers have been implemented, especially in Asia's advanced developing countries. The strategic importance of these new policies is well captured by the report of the US National Science Board (2004, chapter 1, overview, p.8). This report documents that advanced developing countries (primarily in Asia) "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".

But the main concern of the US National Science Board is whether the post-9/11 visa restrictions on foreign students, scholars and engineers will dry up the erstwhile readily available supply of top talent for US firms. The report documents a dramatic decline in the number of visas issued to foreign students, high-tech workers and visiting scholars through two mechanisms – a decrease in the number of applications and a substantial increase in the proportion of visa applications rejected by the US Department of State (US National Science Board, 2004, chapter 3, p.37). This raises an important question for host-country policies in developing economies: can they replicate the earlier US model of attracting top talent from the global market for knowledge workers? Some Asian countries (especially China) are providing lavish incentives (for how long?). But to retain these top talents, financial incentives are not sufficient. Chinese firms need to create attractive, breakthrough, innovation projects that would attract the best engineers and scientists. This requires a quantum leap in the development of local innovative capabilities.

6 Leverage participation in GINs

This section explores what policies host countries can use to enable local firms to leverage participation in GINs to develop their own innovative capabilities. This is the core of successful IU strategies. Innovation is defined as the skills, knowledge and management techniques needed to design, produce, improve and commercialise artefacts, i.e. products, services, equipment and processes (Ernst, 2007a; Ernst, 2007b). A broad definition is used to demonstrate that while R&D is important, innovative capabilities

depend as much on the complementary capabilities needed to implement and commercialise the results of R&D (Teece, 1986).

Host-country policies to develop local innovative capabilities through participation in GINs face substantial challenges. Although TNCs are offshoring routine commodity innovation activities such as implementation services for chip design, they seek to retain control over core IPRs, covering leading-edge process and product technologies, industrial product design and customer relations management. According to the CEO of Motorola, "You have to draw a line – core intellectual property is above it, and commodity technology is below" (*Business Week*, 21 March 2005, p.3). However, the transition to more open innovation systems through GINs reflects the recognition by incumbent market leaders that there is no way to prevent knowledge diffusion (Ernst, 2005b). Even the most aggressive attempts to slow down this diffusion are unlikely to succeed, as the demarcation between core IPRs and commodity innovation work becomes blurred.

To establish what are realistic options for policies to leverage GIN participation, a well-known taxonomy of innovation that distinguishes incremental, modular, architectural and radical innovations (Henderson and Clark, 1990) is used, and is combined with the concept of disruptive technologies (Christensen, 1997). The taxonomy of innovation provides an analytic framework for distinguishing innovative capabilities by complexity. Incremental innovations take the dominant components of design and architecture for granted, but improve on cost, time-to-market and performance. Examples are improvements in process technology such as Dell's innovations in supply chain management or the provision of Original Design Manufacturing (ODM) services by Taiwanese notebook producers. Incremental innovations may also involve continuous improvements in product design that enhance the user-friendliness of a product or service, without any change in components and architecture.

With modular innovation, new component technology is plugged into fundamentally unchanged system architecture. This type of innovation has been a defining characteristic of the PC industry – within each generation of the Intel architecture (combining Microsoft's Windows architecture and Intel's microprocessors), modular innovation introduced new component technology, for instance for memory, storage and display devices.

Architectural innovations use existing component technology but change the way components are designed to work together. Architectural innovations build on a company's familiarity with market trends and user requirements to specify an electronic system, but use existing component technology that is available on the market to implement this design. An important characteristic of architectural innovations is the endless variety of possible approaches. An important example is the commercialisation of government-sponsored, large-scale R&D projects in the Republic of Korea's telecommunications sector, especially the Time Division Exchange (TDX) project that lasted for more than 15 years (Chung et al., 1998; Choung et al., 2003). A similar example is the development of China's electronic switching system HJD04 (Shen, 1999). In both cases, the innovation consists of developing a system architecture that optimises performance features in line with the specific features of the national telecommunications network structure and the specific needs of the service providers.

Other examples of China's successful architectural innovations include the following: the development of Chinese language electronics publishing systems by the Founder Group Company, a spin-off from the Institute of Computer Science and Technology of

Beijing University (Lu, 2000, chapter 4); and the development of the unique Chinese Video Compact Disk (VCD) technology and the successful transition to Chinese Digital Video Disc (DVD) system technology (Lu and Mu, 2003). While these architectural innovations use existing component technology, they nevertheless introduce new and distinct features to existing system architectures.

Finally, radical innovations involve the use of new component technology and changes in architectural design. They typically involve breakthroughs in both areas. Examples include the discovery of new drugs and the invention of the internet. These innovations receive the greatest attention in both the business press and the academic literature. High margins through premium pricing and strong market-entry deterrents are among their powerful attractions. However, radical innovations require an extremely broad base of capabilities in a society, and involve huge risks and extremely high costs of failure. They are thus beyond the reach of most companies in developing countries.

Christensen (1993) uses the Henderson–Clark taxonomy to demonstrate that established, vertically integrated market leaders typically lead the adoption of new component technology, while successful new entrants rely on architectural innovations. Christensen identifies two possible explanations. Firstly, while technological complexity (and hence risk, time and investment expense) are much lower for the architectural design than for the development of new key components, architectural innovations tend to have much more far-reaching implications for market shares and profitability of innovating firms. Secondly, the key to successful innovation is whether there are enough customers who are willing to pay for the new technologies and who can profit from using them.

6.1 The concept of disruptive technologies

The concept of disruptive technologies (Christensen, 1997) deepens the understanding of market constraints. Disruptive technologies underperform relative to established products in mainstream markets today, but they may be fully performance competitive in the same market tomorrow. Disruptive technologies differ from sustaining technologies, which improve the performance of established products that mainstream customers in mainstream markets have traditionally valued. Disruptive technologies bring very different products to a market: they have features that initially only a few fringe (and generally new) customer value. Products based on disruptive technologies are typically cheaper, simpler, smaller and, frequently, more convenient to use. Incumbent market leaders typically fail to notice lower-end markets which may erode their market leadership because they promise lower margins, their most profitable customers generally do not want products based on disruptive technologies and the required break from routine requires a different organisation from sustaining technologies. Most importantly, developing disruptive technologies requires an organisation of innovation projects with substantially lower overheads.

Both innovation taxonomies are useful to examine how host-country policies can enable local firms to leverage participation in GINs as a means of developing their own innovative capabilities. Local firms that are new entrants to a particular product market may face relatively low entry barriers for disruptive technologies, compared with the high entry barriers that they would face for 'sustaining' technologies. Hence, policies that foster architectural innovations and encourage local firms to buy in widely available, existing component technology may make much better sense than a focus on modular or radical innovations.

7 Key findings and policy suggestions

This paper has explored the implications for IU policies that result from innovation offshoring. Much of the analysis has focused on Asia's leading exporting countries of manufactured products. These countries are relatively advanced in the progress they have made in developing their national production and innovation systems. This has enabled them to move from a factor-driven to an investment-driven development strategy. In line with Porter's framework (1990), these countries are now ready to move on to an innovation-based development strategy, and are thus prepared to reap the benefits from participating in GINs, the defining transformation in business organisation that results from the internationalisation of innovation.

The paper demonstrates that the countries that have reached this level of development (e.g. Republic of Korea, China, Taiwan Province of China, India, Brazil, Singapore and Malaysia) have ample opportunities to devise effective policies to maximise the benefits from the internationalisation of innovation. This is so despite the fact that they continue to lag substantially behind the USA and other leading advanced nations in the breadth and depth of their accumulated R&D and innovative capabilities.

7.1 Less-developed countries must pursue aggressive policies

As highlighted in the 2005 report of the UN Millennium Project's Task Force on Science, Technology and Innovation (UN Millennium Project, 2005), most other developing countries may find it much more difficult to realise these potential benefits. An important conclusion that this study draws is that for the majority of developing countries getting host-country policy responses right is even more important than for the above-mentioned relatively advanced countries. These countries need even more than the advanced developing countries to attract R&D by TNCs in order to become better connected to GINs. To make this happen, the less-developed countries need to pursue aggressive policies (preferably as part of regional or multinational collaboration arrangements) to provide specialist public goods (such as education and the development and protection of IPR) and selective incentives.

Another critically important lesson learned from Asian experience is that internationalisation of innovation, and its vertical specialisation within GINs, is driven by a combination of pull, push and enabling factors that are systemic (Ernst, 2005b). For host-country policies, this implies that a narrow focus on demand or supply-oriented forces can only attract foreign R&D if the policies are based on a profound understanding of the underlying changes in the methodology and organisation of the relevant innovation processes in a particular sector. Only when pull, push and enabling factors come together, creating a virtuous circle, host-country policies to attract R&D by TNCs produce the expected results.

Of critical importance is the absorptive capacity of the local firms, i.e. their resources, capabilities and motivations. To stay in the GINs, local firms must constantly upgrade their absorptive capacity by investing in their skills and knowledge base. Equally important are policies to strengthen the innovative capabilities of local firms. As an immediate policy instrument, it is advisable to import missing critical skills from overseas. This could help to catalyse necessary reforms in the domestic innovation system. But most important are support policies for local firms through local supplier development, (co-funded) skill development, standards setting, policies on IPRs and the

provision of investment and innovation finance through a variety of sources, including venture capital, and IPOs.

7.2 Support policies for local firms are critical

To reap the benefits of integration into GINs requires the active involvement of the state (i.e. local, regional and central government agencies, as well as a variety of intermediate institutions). But this involvement now takes on a very different form from the earlier top-down, command-economy-type industrial policies, which were typical for the East Asian development model. With their top-down approach, controlled investment finance and reliance on state-owned enterprises or *chaebol*-type conglomerates, these policies are too rigid to cope with the complex challenges and opportunities of the global network economy that have been explored in this study. Nor can they cope with the conflicting needs of multiple and increasingly vocal domestic actors. In addition, they are unable to deal with the high uncertainty and rapid changes in technology and markets that are typical in the electronics industry. Finally, in light of their protectionist focus, these policies are unlikely to generate and benefit from international knowledge linkages that, as shown in Ernst (2006), have played a critical role in the development of Asian chip-design capabilities.

In short, in order to facilitate a continuous upgrading of local innovative capabilities through participation in GINs, new policy approaches are required that:

- strengthen the state's steering and coordination capacity
- provide public goods in critical bottleneck areas (infrastructure, bottleneck skills, training and education)
- facilitate access to and diffusion of knowledge; balance this with the need to protect IPRs
- encourage overseas investment of leading local companies, to expose them to leading-edge innovation management approaches
- encourage innovations in the financial sector
- generate dialogues at various levels among multiple participants (local and foreign) in production and innovation networks
- foster interactive learning and innovation
- provide social protection and retraining options for the losers of innovation
- facilitate international knowledge sourcing through corporate networks, institutional collaboration and diverse social networks (global knowledge communities and expatriates).

There is, of course, no one optimum formula for such policies. Their instruments and institutions need to vary from sector to sector, in scope, in kind and in impact, as documented in Mowery and Nelson (1999, p.377). The case study of chip design, in Ernst (2005c), has highlighted the peculiar manifestation of GINs, i.e. 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 IT services. For each of these sectors, there are likely to be substantial differences in host-country policy responses to the progressive internationalisation of innovation.

7.3 Policies must vary across countries

Policies also need to differ between countries. A critical prerequisite for finding out more about such policy variations is the construction of relevant country classifications. But most such classifications remain problematic. 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 et al., 2003).

Drawing on Lall (2000), Ernst et al. (1998b), and Ernst and O'Connor (1989), it is possible to suggest a broader country classification scheme that focuses on the following criteria:

- 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. labour and financial markets and education systems)
- social, cultural and political factors that shape national, regional and sector-specific innovation systems.

7.4 Future research

Future research needs to examine what are realistic options for industrial policies for the diverse group of developing countries and how each of these policies can maximise benefits from participating in the GINs of TNCs. For instance, Ernst (2005d) introduces 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 aforementioned UN Millennium Project Report on Science, Technology and Innovation (UN Millennium Project, 2005, p.127) recommends technological diversification as a particularly attractive policy to upgrade innovative capabilities through participation in GINs.

Future research also needs to examine the emerging new geography of innovation and its implications for industrial development in developing countries. The new geography of innovation is not a flatter world. Instead, the concentrated dispersion of GINs creates a handful of new, yet very diverse and intensely competing innovation hubs in Asia (Figure 1).

Future research needs to explore the competitive dynamics that confronts advanced new innovation hubs in Israel, Ireland, Taiwan, Korea and Singapore (as well as possibly Malaysia) with rapidly catching-up locations in China and India, and new locations (e.g. lower-tier cities in China and India, plus Romania, Armenia, Bulgaria, Vietnam, etc.). Each of these diverse locations must find new ways to upgrade through innovation, and they need to develop new policy tools and institutions. While rivalries intensify, these new locations also need to create new space for collaboration on critically important issues such as standard-setting, the reform of the international patent system, as well as the rapidly expanding migration of knowledge workers that might well give rise to a new wave of international 'brain drain' as well as domestic 'brain drain' that occurs when R&D labs established by multinationals absorb the most talented local knowledge workers.

Figure 1 Competing offshore innovation hubs (see online version for colours)

Finally, future research needs to explore, both theoretically and empirically, whether network integration will become a poisoned chalice by stifling domestic innovative capabilities, or whether it will help reduce entrenched barriers to innovation, for instance by strengthening linkages with local universities. It will be imperative for policy-makers to design policies that address these challenges and foster increased network integration, both within and beyond borders.

References

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

Arrow, K.J. (1962, June) 'The economic implications of learning by doing', *Review of Economic Studies*, Vol. 29.

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

Business Week, Special report on 'outsourcing innovation', 21 March 2005.

Choung, J-Y., Min, H.K. and Myung-Chul, P. (2003) 'Patterns of knowledge production: the case of information and telecommunications sector in Korea", *Scientometrics*, Vol. 51, No. 3, pp.115–128.

Christensen, C.M. (1993) 'The rigid disk drive industry: a history of commercial and technological turbulence', *Business History Review*, Vol. 67, pp.531–588.

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

Chung, K.H., Jungwan, H., Seungwoo, S. and Kyeongtaek, K. (1998, November) 'Recommendations from the commercialization of government-sponsored telecommunications R&D with multiple development cycles in Korea', *IEEE Transactions on Engineering Management*, Vol. 45, No. 4, pp.331–337.

Dunning, J.H. (1998) 'Globalization, technology and space', in Chandler, A.D., Hagström, P. and Sölvell, Ö. (Ed.): *The Dynamic Firm. The Role of Technology, Strategy, Organization, and Regions*, Oxford University Press, Oxford, European Defence Agency (EDA) Consortium (2004), Market Statistics Service Survey, San Jose, CA, August, 2004.

Ernst, D. and O'Connor, D. (1989) *Technology and Global Competition. The Challenge for Newly Industrialising Economies*, OECD Development Centre Studies, Paris.

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

Ernst, D., Mytelka, L. and Ganiatsos, T. (1998b) '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*, Chapter 1, Routledge Press, London.

Ernst, D. (2000) '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', pp.223–255.

Ernst, D. (2001, May) 'Global production networks and industrial upgrading – a knowledge-centred approach', *East-West Center Working Papers: Economic Series*, No. 25.

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

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*, co-publication of the World Bank and Oxford University Press, Washington DC, pp.89–157.

Ernst, D. (2005a) '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*, published for the U.S. Social Science Research Council, Princeton University Press, Princeton and Oxford, pp.89–114.

Ernst, D. (2005b) 'From "global factory" to "innovation offshoring": insights from Asia's electronics industry', paper prepared for the UNIDO Project *Global Value Chains and Production Networks: Prospects for Upgrading by Developing Countries*, Vienna, Austria.

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

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, Nos. 1/2, pp.6–20.

Ernst, D. (2006) *Innovation Offshoring – Asia's Emerging Role in Global Innovation Networks* (East-West Center Special Report 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*, Chapter 3, Routledge, Co-published with the Pacific Trade and Development Conference (PAFTAD), London.

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

Ernst, D. and Mowery, D. (2004) *University–Industry Linkages in the Pacific Rim – Public Policy Issues*, East-West Center, Honolulu, HI.

Evans, P. (1995) *Embedded Autonomy. States and Industrial Transformation*, Princeton University Press, Princeton, NJ.

Globerman, S. (1997, August) 'Transnational corporations and international technological specialization', *Transnational Corporations*, Vol. 6, No. 2.

Granstrand, O. (1999) *The Economics and Management of Intellectual Property*, Edward Elgar, Cheltenham.

Grossman, G.M. and Helpman, E. (1991) *Innovation and Growth in the Global Economy*, MIT Press, Cambridge, MA.

Hall, B.H. and Ham, R. (1999) *The Patent Paradox Revisited: Determinants of Patenting in the U.S. Semiconductor Industry, 1980–1994*, NBER Working Paper No. 7062, Cambridge, MA.

Henderson, R.M. and Clark, K. B. (1990, March) 'Architectural innovation: the reconfiguration of existing systems and the failure of established firms', *Administrative Science Quarterly*, pp.9–30.

Hirschman, A.O. (1958) *Strategy of Economic Development*, New Haven, Yale University Press.

Lall, S. (2000) 'Technological change and industrialization in the Asian newly industrializing economies: achievements and challenges', in Kim, L. and Nelson, R.R. (Eds): *Technology, Learning and Innovation. Experiences of Newly Industrializing Economies*, Cambridge University Press, Cambridge, pp.13–69.

Lu, F. and Mu, L. (2003) 'Indigenous innovation, capability development and competitive advantage: the origins and development of the competitiveness of Chinese VCD/DVD industry', unpublished paper presented at *the Annual Meeting of the Business History Conference*, University of Massachusetts at Lowell, MA.

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

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

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

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

Nelson, R.R. (1990) 'Acquiring technological capabilities', in Soesastro, H. and Pangestu, M. (Eds): *Technological Change in the Asia-Pacific Economy*, Allen and Unwin, Sydney.

Nelson, R.R. and Winter, S.G. (1982) *An Evolutionary Theory of Economic Change*, Bellknap Press, Cambridge, MA.

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.

Penrose, E. (1959/1995) *The Theory of the Growth of the Firm*, 3rd ed., Oxford University Press, Oxford.

Porter, M. (1990) *The Competitive Advantage of Nations*, MacMillan Press, London.

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

Richardson, G.B. (1960/1990) *Information and Investment*, Oxford.

Rodrik, D. (1999) *The New Global Economy and Developing Countries: Making Openness Work*, Overseas Development Council Policy Essay No. 24, Johns Hopkins University Press, Baltimore, MD.

Rodrik, D. (2000) 'Development strategies for the next century', paper prepared for presentation at *the Conference on Developing Economies in the 21st Century*, Institute for Developing Economies, Japan External Trade Organization, Chiba, Japan, 26–27 January.

Romer, P.M. (1990) 'Endogenous technological change', *Journal of Political Economy*, Vol. 98, pp.S71–S102.

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.

Teece, D. (1986) 'Profiting from technological innovation', *Research Policy*, Vol. 15, No. 6, pp.285–306.

Teece, D. (2000) *Managing Intellectual Capital*, Oxford University Press, Oxford.

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

US National Science Board (2004) *Science and Engineering Indicators 2004* (NSB 04-1), Vol. 1, National Science Foundation, Arlington, VA.

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

Notes

1 By focusing on knowledge and innovation as major sources of economic growth, the approach in this paper is consistent with leading-edge economic thinking such as endogenous growth theories (Romer, 1990; Grossman and Helpman, 1991) and evolutionary economics (Penrose, 1959/1995; Richardson, 1960/1990; Nelson and Winter, 1982).

2 The other three forms of IU are: (1) inter-industry upgrading from low value-added industries (e.g. light industries) to higher value-added industries (e.g. heavy and higher-tech industries), (2) inter-factor upgrading from endowed assets (i.e. natural resources and unskilled labour) to created assets (physical capital, skilled labour, social capital) and (3) upgrading of demand within a hierarchy of consumption, proceeding from necessities to conveniences to luxury goods. See Ozawa (2000) for discussion on 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 sunset industries and high-wage, high-skill sunrise industries. Such simple

dichotomies, however, have failed to produce convincing results for the following two reasons: (1) 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 such as textiles, and (2) both the capability requirements and the boundaries of a particular industry keep changing over time, which makes an analytical focus on the industry level even more problematic.

3 Most empirical work on IU has explored the expansion of R&D-intensive industries. For most developing countries, that narrow focus is of limited value. The (usually) implicit notion is that potential rates of productivity growth are higher in emergent, R&D-intensive industries (Globerman, 1997; pp.98, 99). Hence, "... specializing in the 'right' technological activities directly contributes to faster growth rates of real income". A related notion is that for R&D-intensive industries, economic rents can be extracted, in part, from foreign consumers. A specialisation in the right technological activities contributes to higher levels of national income by promoting more favourable international terms of trade.