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A New Geography of Knowledge in the Electronics Industry? Asia's Role in Global Innovation Networks

Dieter Ernst

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List of Acronyms

3G	third-generation mobile communication systems
ASIC	application-specific integrated circuit
EU	European Union
FDI	foreign direct investment
GDP	gross domestic product
GIN	global innovation network
GPN	global production network
IC	integrated circuit
IP	intellectual property
IP	internet protocol
IT	information technology
MNC	multinational corporation
ODM	original design manufacturing
OECD	Organization for Economic Cooperation and Development
R&D	research and development

ROI	return on investment
TI	Texas Instruments
TSMC	Taiwan Semiconductor Manufacturing Corporation
UNCTAD	United Nations Conference on Trade and Development
USPTO	United States Patent and Trademark Office

Executive Summary

Political debates about globalization are focused on offshore outsourcing of manufacturing and services. But these debates neglect an important change in the geography of knowledge—the emergence of global innovation networks (GINs) that integrate dispersed engineering, product development, and research activities across geographic borders.

This new form of global corporate networking poses new challenges and opportunities for policy-relevant research on globalization. The challenge is to trace and decipher the increasingly complex forms of these networks, which have expanded well beyond the traditional centers of the global economy in the United States, the European Union (EU), and Japan.

An equally important challenge is to identify the drivers and impacts of these global networks, which are pushing interdependence among national economies and their innovation systems to unprecedented levels. Global corporations construct GINs as they seek to increase their return on investment and penetrate high-growth emerging markets. Although governments until recently have been only marginal players, the global economic recession has forced them to redefine and increase their involvement.

At the same time, the study of GINs provides a powerful tool for sharpening the research agendas of international economics, economic geography, and international relations (and its most recent offspring, global studies) and for developing new policy responses.

The spread of GINs has intensified technology-based global competition, brutally exposing structural deficiencies of current learning and innovation strategies at the firm level and technology policy at the industry level. However, many of these debates are focused on the leading large economies, and the main concern is how to foster breakthrough innovations that can support technology leadership.

This monograph draws on a unique database of GINs in the electronics industry to explore the GINs' drivers and impacts. It specifically highlights Asia's role and discusses how integration of Asian firms into these networks affects learning, capability formation, and innovation. The argument of this study can be summarized as follows:

First, the emergence of GINs is real, and not merely something that can be expected to occur in the future. In fact, we are now in the middle of a rapid expansion of these networks. The main driver of these networks is outsourcing, which draws on the relentless slicing and dicing ("modularization") of engineering, development, and research. This process is complex, involving multiple actors and firms of different sizes, and has resulted in a diversity of networking strategies and network architectures. This study highlights the systemic nature of the forces that are driving and enabling the geographical dispersion of innovation networks.

Second, GINs have expanded well beyond the traditional high-tech regions in the United States, the EU, and Japan. There are now multiple locations for innovation, and even lower-order or less developed centers can still be sources of innovation. Asia's role in these networks—quite minor until recently—is increasing. The resurgence of China and India as important markets and production sites plays an important role in that increase. The speed of learning in some of the new Asian innovation offshoring hubs is impressive, giving rise to increasingly broad-based portfolios of innovative capabilities.

However, the new geography of knowledge is not a flatter world where technical change and liberalization rapidly spread the benefits of globalization. Instead, the offshoring of research and development (R&D) through GINs creates a handful of new—yet very diverse and intensely competing—innovation offshoring hubs in Asia. There is clear evidence that the United States, Europe, and Japan retain their dominance in science and in high-impact intellectual property, enabling them to control the emerging new geography of knowledge.

At the same time, a substantial increase in the mobility of knowledge has led to a concentrated dispersion of innovation hubs. To the degree that the diversity of network players, locations, business models, and network arrangements is increasing, this creates new opportunities for knowledge diffusion, enabling Asian network participants to enhance learning, "absorptive capacity", and innovative capabilities.

This results in a new global hierarchy of innovation hubs:

- Global centers of excellence in the United States, Japan, and the EU
- Advanced locations (e.g., Israel, Ireland, Taiwan, and Korea)
- Catching-up locations (e.g., Beijing, the Yangtze River delta, and the Pearl River delta in China; and Bangalore, Chennai, Hyderabad, and Delhi in India)
- "New frontier" locations (e.g., lower-tier cities in China and India, plus Romania, Armenia, Bulgaria, and Vietnam).

The third argument of this monograph is that the new geography of knowledge cannot be left to market forces alone. The study provides new insights into a critical question that is at the center of Asia's industrial policy debates: is network integration a poisoned chalice for Asian firms, or will it reduce entrenched barriers to innovation? The answer is that there is nothing automatic about these processes. Although integration into global networks of production and innovation has facilitated the catching up of Asian firms as fast followers, that integration may become a mixed blessing unless Asian governments establish appropriate policies for developing absorptive capacity and innovative capabilities both at the firm level and across the industry.

Specifically, this monograph provides evidence for three propositions: 1) "absorptive capacity" is critical for attempts to develop and upgrade innovative capabilities; 2) Asian firms now must increase R&D to avoid diminishing returns of network integration; and 3) integration into diverse networks of production and innovation provide new opportunities for Asian emerging economies to pursue "technology diversification" as a complementary option to "technology leadership" strategies.

Future research needs to address the potentially game-changing impact of the current breakdown of the financial system and the resultant collapse of international trade and investment. There are now clear signs that Asia's prospects for investment and employment are grim and that demand and gross domestic product (GDP) growth will slow down significantly. It is unclear at this stage, however, how this will affect Asia's innovative capacity and its response to the emerging new geography of knowledge.

Future research thus needs to explore whether the crisis will facilitate or disrupt Asia's integration into global networks of production and innovation.

A New Geography of Knowledge in the Electronics Industry?

Asia's Role in Global Innovation Networks

Introduction

Political debates about globalization are focused on offshore outsourcing of manufacturing and services. But these debates neglect an important change in the geography of knowledge—the emergence of global innovation networks (GINs) that integrate dispersed engineering, product development, and research activities across geographic borders. These networks are creating new challenges and opportunities for learning and innovation strategies in emerging economies, yet both firms and policymakers are in the dark about what precisely is required to reap the benefits of these networks.

The spread of GINs has intensified technology-based global competition, brutally exposing structural deficiencies in the role that both the public and private sectors play in the development of national, regional, and sector-specific innovation systems (Tassey 2007: 86). There is a growing recognition that current learning and innovation strategies at the firm level and technology policy at the industry level are showing diminishing returns and should be questioned and revised.

The spread of GINs has intensified technology-based global competition …

However, the discussion of this subject is largely focused on the leading large economies, and the main concern is how to foster breakthrough innovations that can support technology leadership. The prize is to win in the "global innovation race" (Baumol 2002). There is little research on the role of new players from the so-called "emerging economies" in GINs.

This monograph draws on a unique database of GINs in the electronics industry to explore the GINs' drivers and impacts and specifically highlights Asia's role in these networks and how integration of Asian firms into these networks affects learning, capability formation, and innovation.

The monograph focuses on the electronics industry, an industry that is unrivaled in its degree of globalization and thus serves as a testing ground for new forms of global corporate networking strategies. What happens in the electronics industry may well signal future transformations in other industries. Furthermore, emerging economies, especially those in Asia, are playing an increasingly important role as global competitors in this industry.

Competition in the electronics industry is driven by rapid changes in technology and markets and by very short product life cycles. A defining characteristic of the industry is "network externalities" (Katz and Shapiro 1985). A company succeeds "when customers expect that the installed base of … [the company's] … technology [will] become larger than any other," with the result that the customers "adopt that technology to the virtual exclusion of others" (Sheremata 2004: 359). However, network externalities are not sufficient to gain and retain a competitive advantage. Equally important is a capacity to combine cost reduction, speed to market, and product differentiation through significant performance improvements (Ernst 2002b). This capacity requires a broad portfolio of intellectual property (IP) rights and explains why innovation in the electronics industry is *cumulative* rather than *discrete* (as it is for pharmaceuticals and biotechnology).

A second defining characteristic of innovation in this industry is *fragmentation,* or "modularization," and its dispersion across boundaries (of firms, countries, and sectors) through GINs. Progress in the division of labor in design (through modular design) has created opportunities for vertical specialization in both manufacturing and innovation, enabling firms to disintegrate the value chain as well as to disperse it geographically. Increasingly, this process has taken on a global dimension, giving rise first to global production networks (GPNs) and then to GINs.

More recently, modular design has also provided ample opportunities for vertical specialization in the production of knowledge-intensive services, such as software, information services, engineering, and research and development (R&D). Innovation is being sliced and diced into modular building blocks of specialized tasks for geographically dispersed R&D teams. Innovation in the electronics industry thus requires *interoperability* (or "compatibility") standards that enable independently designed products and components to work together within a technological system (e.g., a laptop, a handset, or a switching system). Compatibility standards are the lifeblood of innovation in the electronics industry. They are critical for enabling knowledge sharing through global innovation networks, and they are necessary for the integration of diverse knowledge communities at different locations (Ernst 2005a).

Compatibility standards are the lifeblood of innovation in the electronics industry

The first part of this study, "The New Face of Globalization," summarizes the argument of the monograph. The following part, "Conceptual Framework," introduces taxonomies of innovation and innovative capabilities that are used to examine the drivers of these networks and their impacts. In the third section, "What Do We Know about Global Innovation Networks?" the GIN database is used to establish what is known about these networks in the electronics industry and about Asia's role. Finally, the fourth part, "The Challenge for Asia," discusses how integration of Asian firms into these networks might affect learning, capability formation, and innovation.

The New Face of Globalization

As globalization has been extended beyond markets for goods and finance into markets for technology and knowledge workers, the organizational and geographical mobility of knowledge has increased." (Ernst 2002a, 2003, and 2005d). Global corporations are at the forefront of these developments. Profound changes are transforming their innovation management; an increasing vertical specialization ("fragmentation") of knowledge production has given rise to GINs that integrate dispersed engineering, product development, and research activities across firm boundaries and geographic borders (Ernst 2007b).[1]

This new form of global corporate networking poses new challenges and opportunities for policy-relevant research on globalization. The challenge is to trace and decipher the increasingly complex forms of these networks, which have expanded well beyond the traditional centers of the global economy in the United States, the European Union (EU), and Japan.

An equally important challenge is to identify the drivers and impacts of these global networks that are pushing interdependence among national economies and their innovation systems to unprecedented levels. Global corporations construct GINs as they seek to increase return on investment (ROI) and penetrate high-growth emerging markets. Although until recently governments have been only marginal players, the global economic recession has forced them to reconsider and increase their involvement.

At the same time, the study of GINs provides a powerful tool for sharpening the research agenda of international economics, economic geography, and international relations (and its most recent offspring, global studies) and for developing new policy responses.

The argument of this monograph can be summarized as follows:

First, the emergence of GINs is real, and not merely something that can be expected to occur in the future. The spread of these networks contrasts with a widespread perception that "globalized R&D networks … are still limited in number and mostly concentrated with big firms" (OECD 2008a: page 64). As is so often the case, econometric analysis dominates policy debates, and its findings are inconclusive.[2] This study will show that these networks are in fact rapidly expanding.

The main driver of [GINs] is outsourcing …

The main driver of these networks is outsourcing, which draws on the relentless slicing and dicing ("modularization") of engineering, development, and research. But, as discussed elsewhere (Ernst 2005a, 2005b), the still largely unresolved coordination problems that result from the dispersion of diverse knowledge communities across distant locations pose serious limitations to a progressive modularization of these networks. Of critical importance, especially in the electronics industry, are the limitations to modularity that result from fluid and rapidly evolving interoperability standards.

This study will also show that this process is complex. It involves multiple actors and firms of different sizes, giving rise to a diversity of networking strategies and network architectures. It highlights the systemic nature of the forces that are driving and enabling the geographical dispersion of innovation networks. The systemic nature of the driving forces suggests that we are dealing with lasting changes in the geography of knowledge.[3]

Second, GINs have expanded well beyond the traditional high-tech regions in the United States, the EU, and Japan. There are now multiple locations for innovation, and even lower-order or less developed centers can still be sources of innovation (Cantwell 1995: 172). Much of the current action is in Asia, and especially in China and India.[4]

This study will show that Asia's role in these networks, formerly quite minor, is increasing. However, the new geography of knowledge is not a flatter world where technical change and liberalization rapidly spread the benefits of globalization.[5] Instead, the offshoring of R&D through GINs creates a handful of new—yet very diverse and intensely competing—innovation offshoring hubs in Asia. There is clear evidence that the United States, Europe, and Japan retain their dominance in science and in high-impact IP, enabling them to control the emerging new geography of knowledge.

At the same time, we find a substantial increase in the mobility of knowledge, which gives rise to a concentrated dispersion of innovation hubs. To the degree that the diversity of network players, locations, business models, and network arrangements is increasing, new opportunities for knowledge diffusion, enabling Asian network participants to enhance learning, absorptive capacity, and innovative capabilities have been created.

The new geography of knowledge cannot be left to market forces alone

However, there is nothing automatic about these processes. The third argument of this study is that the new geography of knowledge cannot be left to market forces alone. Although integration into global networks of production and innovation has facilitated the catching-up of Asian firms as fast followers, that integration may become a mixed blessing unless Asian governments establish appropriate policies for developing absorptive capacity and innovative capabilities both at the firm level and across the industry. This suggestion is in line with Kenneth J. Arrow's proposition (established in his classic 1962 paper "The Economic Implications of Learning by Doing") that markets are notoriously weak in generating learning and knowledge, as both are subject to externalities. In other words, R&D investments are typically characterized by a gap between private and social rates of return.

There is still some way to go before there can be a conclusive answer to the question: is network integration a poisoned chalice for Asian firms, or will it reduce entrenched barriers to innovation? This study, however, highlights three propositions: 1) absorptive capacity is critical for attempts to develop and upgrade innovative capabilities; 2) Asian firms now must increase R&D to avoid diminishing returns of network integration; and 3) integration into diverse networks of production and innovation may well provide new opportunities for "industrial upgrading through innovation" that are less costly than the policies described in Tassey (2007). "Technology diversification" that combines incremental and architectural innovations is within the reach of Asian emerging economies and can serve as a complementary option to "technology leadership" strategies.

Conceptual Framework: Innovation and Innovative Capabilities

GINs emerge as a natural extension of GPNs and hence share most of their characteristics.[6] But they also differ. In order to understand what makes them different, one needs to open the black box of "innovation."

> ***GINS [are] a natural extension of GPNs and … share most of their characteristics***

Learning and Innovation

A fundamental insight of innovation theory is that learning and innovation are "the two faces of R&D" (Cohen and Levinthal 1989:

569). Learning by doing establishes routines: "The firm becomes more practiced, and, hence, more efficient, at doing what it is already doing" (ibid.: 570). But a firm's growth depends on a second type of learning (absorptive capacity), by which a firm acquires external knowledge "that will permit it to do something quite different."

For effective conversion of knowledge to productive learning, two important elements are required (Ernst and Kim 2002: 1425): an existing knowledge base or competence and an intensity of effort or commitment. In fact, a critical prerequisite for absorptive capacity is that a firm conducts basic research in-house. This emphasis on reserch differs from the current fashion of "open innovation" (see Chesbrough 2003), which downplays the importance of a decline in corporate basic research. Cohen and Levinthal (1989: 593) demonstrate that a firm needs to sustain a critical mass of internal basic research "to be able to identify and exploit potentially useful scientific and technological knowledge generated by universities or government laboratories, and thereby gain a first-mover advantage in exploiting new technologies." The same is true for "spill-overs from a competitor's innovation."

What exactly, then, is innovation? Schumpeter's distinction between invention and innovation[7] and his focus on "new combinations of existing resources" are a good starting point. To capture the essence of innovation, a broad definition is necessary: innovation converts ideas, inventions, and discoveries into "new combinations of existing resources" that lead to new products, services, processes, and business models. It is important to emphasize that innovation is more than research and product development; that users must perceive an advantage to pay for the innovation; and that entrepreneurs are not just founders of Internet start-ups, but vary in terms of size, business model, and organization.[8]

…innovation is more than research and product development

How Innovations Differ

Innovations differ with regard to opportunities and barriers to learning. They also differ in the capabilities that a firm needs to implement a particular type of innovation. It is useful to distinguish between *incremental, modular, architectural,* and *radical* innovations (Ernst 2008a, drawing on Henderson and Clark 1990).[9]

Incremental Innovations

Incremental innovations take both the dominant component design and architecture for granted, but improve on cost, time-to-market, and performance. Their purpose is to exploit to the greatest extent possible the potential of a given design by introducing relatively minor changes to an existing product or process (Nelson and Winter 1982). These innovations do not require substantial inputs from science, but they do require considerable skill and ingenuity, especially complementary "soft" entrepreneurial and management capabilities, as defined in Ernst 2007a.

Examples of incremental innovations are improvements in the organization of manufacturing, distribution, and support services, such as Dell's "direct sales" model and its integration of factory automation and supply chain management. Other examples are new approaches to subcontracting arrangements, pioneered especially by Taiwanese information technology (IT) firms, like original design manufacturing (ODM), foundry services (for integrated circuit fabrication), and design implementation services. Incremental innovations may also involve continuous improvements in industrial design that help to attract the attention of customers and that enhance the user-friendliness of a product and its performance.

Asian firms are well placed to pursue incremental innovations across all stages of the value chain. They operate in extremely price-sensitive markets, especially in China, but also as suppliers to global industry leaders. They are thus under tremendous pressure to improve on cost, time-to-market, and performance. These normally can be achieved through relatively minor changes to the existing product or production process.

Barriers to such improvements are relatively low, as tools and methodologies are familiar and investments tend to be low and predictable. Most importantly, they build on existing operational and engineering skills as well as on the management of supply chains, customer relations, and information systems.

Modular Innovations

Modular innovations introduce new component technology and plug it into fundamentally unchanged system architecture. They have been made possible by a division of labor in product development: "Modularity is a particular design structure, in which parameters and tasks are interdependent within units (modules) and independent across them" (Baldwin and Clark 2000: 88).

This type of innovation has been a defining characteristic of the personal computer industry: within each generation of the Wintel architecture (combining Microsoft's Windows operating system and Intel's processor architecture), specialized suppliers have introduced new component technology, for instance for memory, storage, and display devices.

The barriers to producing modular innovations are substantial. High technological complexity requires top scientists and experienced engineers in various fields. In addition, investment requirements can be very substantial (up to $4.5 billion for a state-of-the-art semiconductor fabrication plant), as are risks of failure.

These high barriers explain why only a few Asian firms outside Japan have a strong track record in modular innovations. Samsung is the most prominent example, with long list of innovations in core components, such as computer memories, displays, and mobile phone platforms.

Another example is Huawei, China's leading telecom equipment vendor. The company has substantially strengthened its capabilities in software development, with its R&D lab in Bangalore playing an important role.[10] Huawei has also invested heavily in the development of application-specific integrated circuit (ASIC) chips, embedded software, and shared platforms for communication and networking equipment. Until recently, its internal semiconductor design unit supplied no more than 10 percent of the chips the company needs, a share that is expected to increase substantially. After the company had spun off its independent chip design company HiSilicon, Huawei reported the completion of design projects for nearly 100 types of ASIC chips, including critical design platforms for third-generation (3G) mobile communication systems.

Architectural Innovations

Architectural innovations are those "that change the architecture of a product without changing its components" (Henderson and Clark

1990: 9). Examples include Apple's iPod and Research in Motion's BlackBerry, which created new markets for mobile consumer and business gadgets and smart phones, which combine performance features of the phone, the Internet, the camera, and audio-video equipment.

Architectural innovations use existing component technologies but change the way they work together. A defining characteristic is a capacity to leverage a deep understanding of market and user requirements in order to break new ground in product development.

Hence, architectural innovations require strong system integration and strategic marketing capabilities, but they are much less demanding than modular and especially radical innovations in terms of their need for science inputs and investment thresholds.

At the same time, however, architectural innovations tend to have far-reaching implications for the market share and the profitability of innovating firms. As highlighted by Henderson and Clark (1990: 9), architectural innovations can threaten incumbent market leaders; they "destroy the usefulness of the architectural knowledge of established firms, and since architectural knowledge tends to become embedded in the structure and information-processing procedures of established organizations, this destruction is difficult for firms to recognize and hard to correct."[11]

What enables industrial latecomers to pursue "architectural" innovations? By definition, latecomers like Chinese electronics firms lag behind industry leaders in the breadth and depth of their innovative capabilities. Their strength, however, is their familiarity with China's markets and institutions and exposure to user requirements that global industry leaders have neglected. Chinese firms might be able to use this knowledge to penetrate its large mass markets. Doing this requires a change in the architecture of a product or service but not new components. They can buy these components from specialized suppliers.

An early example is the development of China's electronic switching system HJD04; the innovation is a system architecture that optimizes the specific features of the national telecommunications network to match the specific needs of the service providers (Shen 1999). Other examples are the development of Chinese-language electronics publishing systems by the Founder Group Company (Lu 2000: chap. 4) and the development of the unique Chinese video compact disk technology.[12]

Radical Innovations

Finally, radical innovations involve both new component technology and changes in architectural design. Examples include the discovery of new drugs and the invention of the microprocessor and the Internet.

The great attraction of radical innovations for new entrants is that once they have intellectual property rights for a blockbuster technology, they may become a market leader in a short period of time.[13] The flip side, however, is that radical innovations require breakthroughs in both architectural and component technology. Radical innovations require dense interaction with leading-edge science, requiring top scientists and engineers who work at the frontier of basic and applied research in a broad range of disciplines. In addition, implementing radical innovations requires a broad set of complementary assets (as defined by Teece 1986), and investment thresholds tend to be extreme.

In short, such innovations are costly and risky, and failure can destroy even large, well-endowed companies. They are beyond the reach of most companies in Asia (outside Japan and Korea), but they may well be the subject of public-private consortia coordinated by the government. In China, an interesting example is the development of the "pebble bed" reactor, which offers the hope of cheap and safe nuclear power stations.

Another example is China's decision to develop by itself supercomputers, in response to the technology export control imposed by organizations of the most developed countries, such as the Coordinating Committee for Multilateral Export Controls. That strategy did produce some tangible results. China's most powerful supercomputer, Dawning's 4000A, was ranked tenth in the world as early as 2004. Its grid-oriented AMD 64 PC-Cluster design uses some unique features, which allows for a theoretical peak performance of twenty-two teraflops (10^{12} floating point operations per second). This is quite an achievement for a company that pales in size relative to global industry leaders and that has only limited financial and human resources. Of critical importance were close links with the Institute of Computing Technology of the Chinese Academy of Sciences, whose president chairs the board of Dawning. But to keep up with the accelerating pace of high-end computing technology will require increasingly large resources.

A similar story of impressive yet costly achievements emerges from Lenovo's supercomputer projects (Ernst 2008a). The first project was the DeepComp 1800 supercomputer, introduced in 2001, which, based on 526 Intel Xeon processors, was ranked fifty-first by 2002. This was followed, in November 2003, by the DeepComp 6800 model, which was ranked fourteenth worldwide and was jointly funded by the Ministry of Science and Technology and the Chinese Academy of Sciences.

Finally, the most recent project, the 1000 TFLOPS supercomputer, which was started in 2005 and is scheduled for completion before 2010, is supposed to be nearly ten times as powerful as the world's fastest supercomputer. But resource requirements are also growing. The reason for developing the computer was clearly more political than commercial, driven by the perception that China cannot rely on other countries to develop a supercomputer that meets its needs.

In short, for latecomer firms, radical innovations pose a difficult challenge. Investment requirements are huge and require substantial government support, while markets are likely to be limited. There may, however, be indirect commercial benefits, as successful completion of a radical innovation project may help to establish a company as a serious player and improve its brand image.

… for latecomer firms, radical innovations pose a difficult challenge

Innovative Capabilities

To determine what kinds of capabilities are required to foster these four types of innovation, we can draw on some building blocks provided in the literature. Patent data analysis can now be used as a proxy indicator for measuring progress in Asia's innovative capabilities, as "patenting activities in the region appear to have grown to sufficiently high levels" (Wong 2006: 11).

Specifically, the analysis of patents filed at the United States Patent and Trademark Office (USPTO) can help to identify the location of an invention (address of first-named inventor) and the nationality of the patent owner (location of assignee). U.S. patent data analysis can also help to determine the quality and impact of patents (patent citations) and their complexity (science-intensity), the clustering/geographic dispersion of patenting activities (by measuring "hot spots"), and the knowledge exchange between inventors at different locations.

Particularly useful for our purposes is research that, based on questionnaire surveys and structured firm interviews, has developed operational data sets for measuring firm-level innovative and R&D capabilities.[14] For instance, a comprehensive taxonomy of firm-level capabilities was developed in a study, prepared for the United Nations Conference on Trade and Development (UNCTAD), that distinguishes capabilities required for production, investment, minor change, strategic marketing, establishing interfirm linkages, and major change (Ernst, Ganiatsos, and Mytelka 1998).[15]

Building on that literature, this study suggests using a broad definition of "innovative capabilities" to emphasize that, in addition to R&D and patents, complementary "soft" entrepreneurial, management, and system integration capabilities are of critical importance. Here "innovative capabilities" are defined to include the skills, knowledge, and management techniques needed to successfully create, change, improve, and commercialize "artifacts," such as products, services, equipment, processes, and business models (Ernst 2007a).

This study suggests using a broad definition of innovative capabilities

Innovations require R&D capabilities, especially in high-tech industries. As discussed in "Technology Leadership Is Not the Only Option," below, basic research is critical for radical innovations, while the other three types of innovation require applied research and product development. Yet case studies of successful innovations in the electronics industry demonstrate that the technology is the easy part to change. The difficult aspects are social, organizational, and cultural. In order to create products and services that customers are willing to pay for, the following "soft" innovative capabilities are critical. The ability to:

- sense and respond to market trends before others take note ("entrepreneurship");
- recruit and retain educated and experienced knowledge workers who are the carriers of new ideas;
- engage in the global sourcing of knowledge for core components, reference designs, tools, inventions, and discoveries;

- raise money required to bring an idea quickly to the market (the litmus test of innovation);
- deliver unique and user-friendly industrial designs (which is of critical importance especially for fashion-intensive consumer devices, like mobile handsets);
- develop and adjust innovation process management (methodologies, organization, and routines) in order to improve efficiency and time-to-market;
- manage knowledge exchange within multidisciplinary and cross-cultural innovation projects;
- participate in and shape global standard setting;
- combine protection and development of intellectual property rights; and
- develop credible and sustainable branding strategies.

Each of these "soft" capabilities is important individually. And this is true for all four types of innovation. But "soft" capabilities also depend on one another. For instance, a narrow focus on brand marketing is insufficient without innovation. Hence, branding efforts need to be supported by a broad mix of "soft" and "hard" innovative capabilities. In addition, a capacity to provide "integrated solutions" is arguably one of the most important prerequisites for successful innovation.

According to Davies et al. (2001: 5), integrated solutions encompass four sets of capabilities: 1) system integration: to design and integrate components and subsystems into a system; 2) operational services: to maintain, finance, renovate, and operate systems through the life cycle; 3) business consulting: to understand a customer's business and to offer advice and solutions that address a customer's specific needs; and 4) finance: to provide a customer with help in purchasing new capital-intensive systems and in managing a customer's installed base of capital assets.

By and large, global corporations from the United States, Japan, and the EU, as well as from Korea and Taiwan, have sophisticated and proven strategies in place that can provide simultaneously these four complex integrated solutions services. But in most other Asian countries, including China and India, even leading companies have still some way to go to develop the four sets of integrated solutions capabilities.

What Do We Know about Global Innovation Networks?

A Taxonomy

A defining characteristic of the new geography of knowledge is that both learning and innovation are fragmented ("modularized") and geographically dispersed through multilayered global corporate networks that integrate engineering, product development, and research activities across firm boundaries and geographic borders. It took some time for economic theory to adjust to this important transformation.

Until recently, research on the geographical distribution of patents concluded that innovative activities of the world's largest firms were among the least internationalized of their functions (Patel and Pavitt 1991). This finding gave rise to the proposition that innovation, in contrast to most other stages of the value chain, is highly immobile: it remains tied to specific locations, despite a rapid geographic dispersion of markets, finance, and production (see, e.g., Archibugi and Michie 1995). Attempts to explain such spatial stickiness of innovation have highlighted the dense exchange of knowledge (much of it tacit) between the users and producers of the resultant new technologies (see, e.g., Feldman 1999; Porter and Sølvell 1998).

Yet, even as this research was in progress, the world was changing, with the emergence of GINs in the 1990s and 2000s that carry out design and product development as well as applied and basic research. GINs share three important characteristics with the GPNs that preceded them (Ernst 2002b, 2006, and 2007b):

- *Asymmetry* is a fundamental characteristic. Multinational corporations (MNCs) dominate as network flagships and define network organization and strategy. Control over and coordination of network resources and decision making enables the flagship to directly affect the growth, strategic direction, and network position of lower-end participants (e.g., specialized suppliers and subcontractors).
- A great variety of *governance* structures is possible. These networks range from loose linkages that are formed to implement a particular project and that are dissolved after the project is finished—so-called "virtual enterprises"—to highly formalized networks, "extended enterprises," with clearly defined rules,

common business processes, and shared information infrastructures. What matters is that formalized networks do not require common ownership; these arrangements may, or may not, involve control of equity stakes.

- *Knowledge sharing* is the glue that keeps these networks growing. Of course, the primary purpose of GINs is to help flagships to gain quick access to skills and capabilities at lower-cost overseas locations that complement the flagships' core competencies. As the flagship integrates geographically dispersed innovation clusters into GINs, this may well produce cost savings. Yet the real benefits of globalization result from the dissemination and exchange of knowledge and complementary capabilities. Network flagships increasingly rely on the skills and knowledge of specialized foreign subsidiaries and suppliers to enhance their core competencies. Network flagships not only gain access to skills and capabilities at lower costs, but, perhaps far more importantly, they gain access to different ideas and ways of doing things, including new "hybrid" business models. Such diversity may enhance the flagship's scope for innovation.

Knowledge sharing is the glue that keeps these networks growing

Five types of GINs can be distinguished (see table 1). This study focuses on the first three corporate networks. The fourth type of GINs is international public-corporate R&D consortia. This type of GIN is likely to increase in importance in response to the global recession that started in 2008. In addition, formal corporate GINs are complemented by a sea of informal social networks within and across specialized knowledge communities that facilitate the transmission and sharing of critical tacit knowledge (Powell and Grodal 2004).

… formal … GINs are complemented by a sea of informal social networks …

The Measurement Problem

Extensive efforts have been made to improve the measurement of innovation.[16] Yet good data on the international dimension of innovation

Table 1. Global Innovation Networks: A Taxonomy

- **Intrafirm Networks –** Global companies "offshore" stages of innovation to Asian affiliates
- **Intrafirm Networks –** Global firms "outsource" stages of innovation to specialized Asian suppliers
- **Asian firms** construct their own (mostly intrafirm) networks
- **International public-corporate R&D consortia**
- **Informal social networks** (students, knowledge workers)

remain extremely hard to find. There is a dearth of adequate indicators and methods to assess and analyze the transformations that are driving the emerging new geography of knowledge. We still lack a robust set of operational measurements to trace the growing exchange of technology, information, and knowledge across borders that are critical for most innovation projects.[17]

good data on the international dimension of innovation [are] hard to find

This measurement problem is particularly serious when one tries to assess the importance of GINs. According to a recent study by the Organization for Economic Cooperation and Development (OECD), *The Internationalisation of Business R&D* (OECD 2008b: 59), "information about such networks is fragmented and uncertain." Econometric analysis dominates and focuses on a narrow set of highly aggregate data that are often lagging by a number of years. The findings remain inconclusive. According to Jeff Macher, David Mowery, and A. D. Inin (2007: 2), "imperfect proxies" provide a picture of a "surprisingly low level of globalization."[18]

Nevertheless, the scattering of the innovation process across borders shows up even in some of those imperfect proxy indicators. For example, IMF Balance of Payment data document a rapid growth of international payments for intangible intellectual property, especially technology licensing. And a recent survey, to take another data point, shows that the world's leading R&D spenders are increasing both offshoring and outsourcing of innovation activities to Asia, especially to

China and India (UNCTAD 2005).[19] By 2004 China had become the third most important location for overseas R&D affiliates, after the United States and the United Kingdom, followed by India (sixth) and Singapore (ninth). More than half of the responding firms have at least one R&D facility in China, India, or Singapore. The same survey projects that the pace of R&D internationalization will accelerate, especially among U.S.-, Japanese-, and Korean-headquartered firms. As many as 67 percent of the respondents to the UNCTAD survey stated that the share of foreign R&D will increase; only 2 percent indicated the opposite.

Rigorous case studies of company-specific GINs are needed …

There is no doubt, however, that such proxy indicators are insufficient to shed light on what is really happening. Rigorous case studies of company-specific GINs are needed to provide richer, more current, and more persuasive data.

The GIN Database

We now have a tool for such research: a unique GIN database of global innovation networks for a sample of almost 150 companies in the information and communications technology industry. The development of that database draws on the author's research on the evolution of global networks of production and innovation (e.g., Ernst 1997, 2002b, and 2007b). The database draws on questionnaire surveys and case studies. This research has two objectives: 1) to identify drivers and characteristics of diverse GINs; and 2) to assess the impacts of these networks on learning, capability formation, and innovation at diverse locations in China, Taiwan, Korea, and India.

The questionnaire surveys and case studies provide basic information (some quantitative, but mostly qualitative) on the location and type of activity of offshore R&D labs, date of establishment, the size and composition of the workforce, and the educational background and work experience of senior managers. In addition, the database contains information on:

- the rationale for establishing a GIN rather than following a traditional integrated model;
- the scope and stability of these networks and their governance;

- management practices to implement network coordination;
- approaches to learning and knowledge sharing;
- the types of innovation and innovative capabilities at different network locations and their interaction.

For instance, on the last topic, the surveys asked the following questions:

- Which of the following innovations are you pursuing: incremental, modular, architectural, or radical?
- Are you pursuing innovations that are incompatible with dominant standards?
- What is the relative importance of these different types of innovation?
- Do different types of innovation require different approaches to network architecture and organization?
- What management practices are in place regarding intellectual property?
- How important are interoperability standards?
- Are you primarily a standards taker, or are you also a standards setter?
- Do different approaches to standards require different approaches to network architecture and organization?

To address this research agenda for the above three types of corporate GINs, it was necessary to design a company sample that is highly diverse in terms of size, ownership, business model, and nationality. The sample includes large global brand leaders from the United States, Asia, and Europe, as well as specialized suppliers of technology, core components, and product development services. Also collected were profiles of mini-GINs for small transpacific start-up companies of foreign-born engineers from Taiwan, China, and India that are headquartered in Silicon Valley. The interesting thing about these start-ups is that they had to commit to conducting product development and research work in Asia in order to receive venture capital funding.

Collecting these data is a time-consuming and costly affair. Obviously, the size of the sample remains small compared to the large population of IT companies with global operations. However, the database is representative, capturing important protagonists that shape the dynamics of GINs in the electronics industry and providing important qualitative insights into the nature of these global transformations.

Given how little is known about GINs, it is appropriate at this stage to pursue an "interpretative" approach to case study research (Walsham 1993: 4–5). The main purpose is to understand the context, drivers, and impacts of GINs. This goal is in line with established case study research methodology. According to Eisenhardt (1989), a case-based qualitative study is suitable for descriptive purposes and appreciative theory building, in which "how" and "why" questions are the most urgent ones to answer (Yin 2009).[20]

How Important Is Asia?

Asia's role in intrafirm GINs of global industry leaders is increasing, although it is starting from a low level. The resurgence of China and India as important markets and production sites obviously plays an important role. The speed of learning in some of the new Asian innovation offshoring hubs is impressive, giving rise to increasingly broad-based portfolios of innovative capabilities. Asia's new innovation hubs (both the advanced locations in Taiwan and Korea, and the catching-up locations in China and India) are rapidly moving up the learning curve and execute increasingly complex projects.

Asia's role in intrafirm GINs of global industry leaders is increasing

There is clear evidence that these networks remain hierarchical, as control over critical resources and strategic direction remains highly unequal.[21] Our interviews show that most of these new Asian labs remain focused primarily on repetitive detailed engineering and product development tasks.[22] These labs are of relatively low strategic importance, as evidenced by their vulnerability to budget cuts decided by headquarters. Asia's role in these labs is confined to the provision of lower-cost skills, capabilities, and infrastructure. While dense information flows link these labs with R&D teams at headquarters and other affiliates, knowledge exchange remains tightly controlled and highly unequal.

In short, the defining characteristic of an intrafirm GIN is a persistent inequality in the division of innovation tasks. A handful of established global centers of excellence in the United States, Japan, and the EU retain their dominance in science and high-impact intellectual property, and hence continue to shape technology roadmaps through radical and architectural innovations.

Looking at the Bangalore labs of three global industry leaders—Texas Instruments (TI), Cisco, and Intel—provides an idea of Asia's role in intrafirm innovation networks.[23] These three prominent examples signal the speed and depth of Asia's integration into global innovation networks, but they also indicate that there is still a long way to go before Asia's new hubs become equal partners.

Established in 1985, Bangalore is TI's largest lab outside the United States, with a workforce of more than 2,800. Since 1998, this lab has conducted integrated development projects for highly complex system-on-chip design. Since 2003, TI Bangalore has been assigned the global product development mandate for leading-edge single-chip modems. TI Bangalore also claims that it is co-developing ("co-architecting") 3G wireless chipsets. Furthermore, TI Bangalore claims that it has successfully completed more than 500 patent filings at both the USPTO and the European Patent Office.

As for Cisco, Bangalore is its largest lab outside the United States, with a workforce of more than 3,200. Cisco Bangalore claims to have developed strong capabilities in software development for optical networks, Internet operating systems, Voice over Internet Protocol, and the design of application-specific integrated circuits. The Bangalore lab is involved in the co-development of optical networks and leading-edge router platforms. Cisco Bangalore claims to have successfully filed more than 500 USPTO patent grants.

Until 2007, Cisco's headquarters in San Jose, California, decided Bangalore's R&D agenda. Cisco claims that this is now beginning to change, as Bangalore has become Cisco's second global headquarters. As part of a more equal partnership, Cisco Bangalore claims to be involved in breakthrough innovations for low-cost systems and integrated solutions.

As for Intel, its R&D activities are expanding most rapidly in India and China. However, Intel's U.S. labs in Santa Clara and Folsom, California, and Austin, Texas, remain the primary locations for core technology development and applied research, while Haifa, Israel (established as early as 1974) is focused on processor research and Nizhny Novgorod, Russia, on software development.

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

A closer look at Intel Bangalore shows substantial progress in the portfolio of innovative capabilities, but it also reveals a persistently hierarchical division of labor. Since its establishment in 1998, Intel Bangalore claims to have contributed to the design of successive Intel microprocessor platforms, as well as the design and validation of increasingly complex multicore processor families. Two widely reported projects are symptomatic. In June 2004, about 500 technical staff at Intel Bangalore started to design parts of the Centrino Duo platform. And in September 2008, Intel Bangalore claimed the first "complete" design of Intel's newly launched Xeon 7400 microprocessor.

Both projects are real achievements for the Bangalore design teams. They indicate substantial progress in innovative capabilities, especially in the critically important "soft" capacity to provide integrated solutions.

The Centrino Duo platform comprises the Centrino Duo processor, the 945 Express peripheral logic chips, and the PRO/Wireless 3945ABG wireless LAN connection. The key challenge for designing this platform is to reduce trade-offs between performance, miniaturization, and power consumption. Hence, complex engineering problems had to be solved under tremendous time pressure and within tight financial constraints. For this to happen, Intel Bangalore had to make substantial contributions to architectural design. However, key parameters of the processor architecture were determined by Intel's core labs in the United States. In addition, Intel Bangalore made important contributions in software development, validation, and platform testing, as well as in designing some parts of the customer interface of this platform. As one observer put it, Intel Bangalore's main contribution is in "making the processors market ready."[24]

As for the Xeon 7400 microprocessor, it is used primarily in server farms and other transaction-processing applications. Lower power and parallel processing are the most important attributes of the Xeon architecture. The Xeon 7400 seems to be yet another derivative of Intel's basic multicore architecture approaches, and the basic architecture has been developed entirely in the United States.

Intel Bangalore's contribution was mostly an integration effort. Bangalore's strength lies primarily in the so-called backend design tasks, which includes reverifying the design, chip layout, running manufacturability tests, and performing product engineering. According to one source, who requested anonymity, "These tasks are mostly tedious and require intense manpower to complete the tasks. The intellectual content, i.e., inventing new techniques and architectures, is low. No new core design was done to complete the project."

… GINs [can] act as vehicles for accelerated learning and capability development.

In short, these two examples show the significant potential of GINs to act as vehicles for accelerated learning and capability development. They also, however, demonstrate that the unequal divide between architectural and other design and development tasks remains as deeply entrenched as ever.[25]

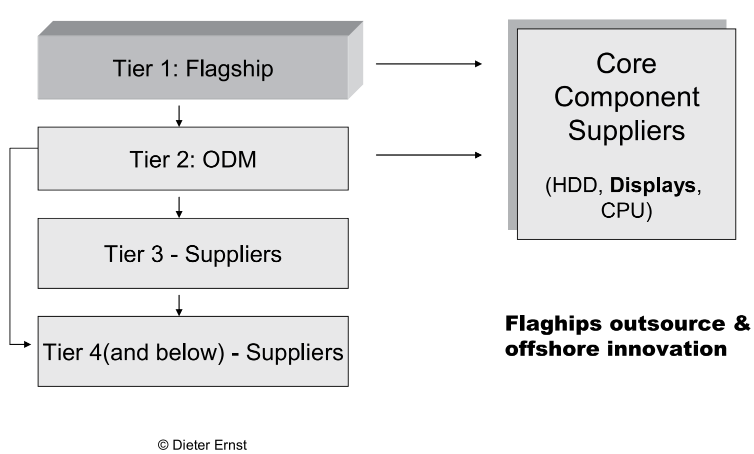
Another important finding on Asia's role in intrafirm networks is the role played by start-up companies in Silicon Valley. These companies now have to commit to conducting product development and research work in Asia in order to receive venture capital funding.[26] The emerging business model is to keep strategic management functions such as customer relations and marketing, finance, and business development in Silicon Valley, while moving product development and research work to Beijing, Shanghai, Bangalore, and other places in Asia. As a result, new and unconventional business models of innovation offshoring have emerged that frequently involve foreign-born engineers from Taiwan, China, and India.

An example is a start-up company in Shangdi Information Industrial Base in Beijing's Haidian District that specializes in mixed-signal chip design. Chinese engineers who hold PhD degrees from leading U.S. universities and have worked as senior project managers in leading U.S. semiconductor companies founded the company. The company has received venture capital funding for developing chip designs in both China and Silicon Valley. A fully integrated design team in Beijing develops decoder chips customized for the new Chinese AVS (audio-video signal) standard. Of the more than sixty engineers at the Beijing facility, 90 percent hold at least master's degrees. Five senior managers based in Santa Clara handle customer relations and provide design building blocks (so-called silicon intellectual properties) and tool vendors for design automation, testing, and verification.

Offshoring brokers are emblematic of the fine-grained division of labor in innovation offshoring. They provide another important approach for start-ups based in Silicon Valley. A typical example is a company, based in Santa Clara, California, and Ahmedabad, India, which was founded by an Indian design engineer with a distinguished track record in leading U.S. semiconductor firms. The company was established specifically to work as an offshoring broker to the U.S. semiconductor industry. It started out testing designs, but it has since expanded its services considerably and now provides everything from system design to the development of design building blocks of integrated circuits. The company's main focus, however, is to help U.S. semiconductor firms run R&D teams in India in a manner that minimizes risks of disruption and bridges potential communications gaps.

Turning to the second type of GIN, global firms also outsource some stages of innovation, especially those related to product development, to specialized offshore suppliers as part of complex interfirm GINs. For example, global brand leaders for laptops (like Hewlett-Packard, Dell, Acer, and Lenovo) use design services provided by so-called original

Figure 1. Inter-Firm Networks - Notebooks



design manufacturers (ODMs), mostly from Taiwan, for new product development (see figure 1).[27] 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 differ drastically 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 United States, Japan, and the EU. However, there are also now network flagships from Asia (outside Japan). New Asian players develop their own networks and unique ("hybrid") networking strategies.

Over time, an increasing diversity of GINs has emerged

Table 2 shows an example of a global innovation network for handsets, established by a Chinese telecommunications service provider. As a network flagship, China Mobile determines the strategic direction of this

Table 2. Global Innovation Network: Handsets
Telecom service provider defines system architecture (China Mobile) ■ suppliers of handsets & components (Tw, Kr, China) ■ suppliers of design platform (IDM: US, EU, Kr; design houses: US, Tw, China) ■ IP providers (UK, Tw) ■ SW providers: OS/MMI/GUI (India, Tw, US) ■ foundries (Tw, Sing, China) ■ chip packaging companies (Tw, Kr, China) ■ tool vendors for design automation & testing (US) ■ design support service providers (various Asian countries)
Note: EU = European Union; GUI = graphic user interface; IDM = integrated device manufacturer; Kr = Korea; MMI = a special technique of printed circuit design; OS = operating system; Sing = Singapore; SW = software; Tw = Taiwan; UK = United Kingdom; US = United States.

network, and it controls key resources. The network consists of eight layers of specialized suppliers, most of them from Asia (outside of Japan).

MediaTek Taiwan, the world's fourth largest chip design company, provides another example of an Asian GIN (see table 3). The company designs integrated circuits (ICs) and chipsets for mobile handsets. MediaTek received its core technologies from participation in R&D consortia, coordinated by the Industrial Technology Research Institute. Most importantly, the company decided to tap into a lower-cost source of licensing for transmitter and receiver technology. Instead of relying on Qualcomm, the industry leader that is well known for charging high licensing fees, MediaTek selected Silicon Image, a Silicon Valley–based company that was willing to provide more attractive terms. MediaTek's business model focuses on cost competition. Its price quotes are typically more than 10 percent below the quotes of global industry leaders such as Qualcomm, TI, and ST-NXP.

To enter the market, MediaTek initially focused on providing low-cost platforms for Chinese no-name (so-called "white box") handset makers. Since 2007, MediaTek has been able to win orders from China's top branded handset makers. In addition, the company has now received orders for smart phones from global industry leaders like

Table 3. MediaTek: Global Innovation Network

Austin, US	DSP R&D
Hsinchu, Taiwan	HQ, R&D digital and analog IC
Shenzhen, China	SW tools and application development
Noida, India	SW for mobile handsets: MMI, etc.
Norwood, US	SW (*former ADI R&D lab)*
Singapore	analog, mixed-signal SoC design and analog layout and digital physical design
Tokyo, Japan	research center
Wilmington, US	Digital & analog/mixed-signal design (*former ADI R&D lab)*

Note: ADI = a U.S. chip design company; Ch = China; DSP = digital signal processor; HQ = headquarters; IC = integrated circuit; MMI = a special technique of printed circuit design; R&D = research and development; SoC = system-on-chip; SW = software development

Samsung and Vodafone. To cope with this rapid upgrading of markets and technology, MediaTek has constructed a GIN, with leading-edge research conducted in the United States at labs that used to belong to ADI, a U.S. company that MediaTek acquired in 2008.

Huawei, China's leading telecommunications equipment producer, provides an example of a highly sophisticated Asian GIN (see table 4). The company has pursued a two-pronged strategy (Ernst and Naughton 2007): it is building a variety of linkages and alliances with leading global industry players and universities, while concurrently establishing its own global innovation network. In fact,

Huawei [is] an example of a highly sophisticated Asian GIN

Table 4. New Players: Huawei

Kista/Stockholm, Sweden

- base station architecture and system design; analog–mixed signal design (RF); algorithms; 3GPP (standards)

Moscow, Russia

- algorithms; analog–mixed signal design (RF)

Bangalore, India

- embedded SW and platforms

Plano, Texas (Dallas telecom corridor)

- total solutions for CDMA; G3 UMTS; CDMA Mobile Intelligent Networks; mobile data service; optical; VoIP

Joint R&D labs with

- Vodafone, British Telecom, Telecom Italia, France Telecom, Telefonica, Deutsche Telekom

Note: E3GPP = Third Generation Partnership Project to develop mobile telecommunications technology; CDMA = second-generation mobile communication standard developed by Qualcomm; G3 = third-generation mobile communication systems; RF = radio frequency; SW = software development; UMTS = Universal Mobile Telecommunications System, a third-generation mobile telecommunications technology; VoIP = Voice over Internet Protocol.

Huawei 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 third-generation mobile communications standard) and 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 United States (Plano, Texas, and San Jose, California), Sweden (Kista, Stockholm), Moscow, and the United Kingdom (as part of British Telecom's list of eight preferred suppliers for the overhaul of its fixed-line phone network).

The choice of these locations reflects Huawei's objective to be close to major global centers of excellence and to learn from incumbent industry leaders: Plano, Texas, is one of the leading U.S. telecom clusters centered on Motorola; Kista, Stockholm, plays the same role for Ericsson and, to some degree, Nokia; and the link to British Telecom was Huawei's entry ticket into the exclusive club of leading global telecom operators.

The Systemic Nature of Driving Forces

Global corporations construct GINs to cope with increasing pressures to internationalize innovation. Specifically, these networks are expected to:

- enable global corporations to increase the ROI on R&D, despite the rising cost, complexity, and uncertainty of R&D;
- facilitate penetration of high-growth emerging markets in compensation for the slow demand growth in core OECD countries;
- accelerate speed to market in line with shorter product life cycles;
- gain access to lower-cost pools of knowledge workers;
- tap into the resources and innovative capabilities of new competitors and emerging new innovation hubs; and
- bypass regulations that seek to protect society (especially the losers of globalization) and the environment.

Here are a few illustrative examples from the company interviews. Table 5 shows a typical formula for calculating ROI in the semiconductor industry (Ernst 2005a). As cost reduction through automation has focused on manufacturing, further improvements in ROI require substantial improvements in the productivity of R&D.

Table 5. Development Cost for Chip Design

$$ROI = \frac{volume \times (sales\ price - manufacturing\ cost)}{development\ cost}$$

- cost of employing design engineers
  = *salary, benefits, equipment, office space, and infrastructure*
- engineering time
- discounted capital costs of engineering tools
- NRE fees paid for design and prototyping services
- mask charges
- IP licensing fees
- risk associated with delayed market entry opportunity costs—key management or engineering resources are tied up with design offshoring

Note: IP = intellectual property; NRE = non-recurring engineering expenses; ROI = return on investment.

As expected, global firms are attracted by supply-oriented forces, especially the lower cost of employing a chip design engineer in Asia, which is typically between 10 and 30 percent of the cost in Silicon Valley. However, demand-oriented factors are equally important. Asia has become the "global factory" which necessitates a progressive localization of engineering, product development, and (at minimum) select research activities. In addition, global firms emphasize the need to relocate R&D to be close to the rapidly growing and increasingly sophisticated Asian markets for communications, computing, and digital consumer equipment to be able to interact with Asia's lead users of novel or enhanced products or services. The main prize is the sheer size of China's market, which provides:

- the largest market for telecom equipment (wired and wireless) and may become a test bed for fourth-generation (4G) mobile communication systems;
- the largest market for semiconductors and handsets;
- the second-largest market for cars and digital consumer electronics;

- a major export market for the United States, Japan, Taiwan, and Korea;
- "bottom- of-the-pyramid" markets for less overengineered products and services with substantially lower costs of acquisition and operation.[28]

Furthermore, there have emerged in Asia, and especially in China and India, new competitors that are accumulating resources and innovative capabilities that are attractive to global corporations. For instance, it is projected that by 2010 China will produce more science and engineering doctorates than the United States (Freeman 2005; National Science Board 2008).[29] In addition, China's areas of scientific excellence now include materials science, especially nano-science, where China ranks third (after the United States and Japan) in the number of nanotech publications, and where the Chinese Academy of Science is ranked fourth for nano-science citations, after the University of California at Berkeley, MIT, and IBM. China's researchers now also excel in areas like voice and image recognition, computer graphics, analytical chemistry, rice genomics, and stem cell biology.

Enabling Factors

At the same time, a powerful mix of enabling factors facilitates the construction of GINs by reducing uncertainty, as well as transaction and coordination costs. The result has been a rebalancing of the centripetal forces that keep innovation tied to specific locations and the centrifugal forces that place a premium on geographical dispersion. The latter have become more powerful, although the former have hardly disappeared.

There are two root causes of this rebalancing and the resultant increase in the mobility of knowledge: 1) the improvement of the information and communication infrastructure and its extension around the world, and 2) the liberalization of international economic policies that allows this technological change to be exploited more fully by firms and organizational networks.[30]

Institutional change through liberalization has played an important role in reducing constraints on the organizational and geographical mobility of knowledge.[31] Hence, liberalization has acted as a powerful catalyst for the expansion of GINs.

The overall effect of liberalization has been to reduce the cost and risks of international transactions and to increase considerably international liquidity. Global corporations have been the primary beneficiaries. Liberalization provides them with:

- a greater range of choices for market entry, whether via trade, licensing, subcontracting, or franchising (*locational specialization*);
- better access to external resources and capabilities that they may need to complement their core competencies (*outsourcing*); and
- fewer constraints on the geographic dispersion of the value chain (*spatial mobility*).

Technology, especially the rapid development and diffusion of information and communication technology, has also increased the mobility of knowledge. The high cost and risk of developing IT has forced companies to search for lower-cost locations for R&D. Equally important is that IT and related organizational innovations provide effective mechanisms for constructing flexible network arrangements that can link together and coordinate economic transactions among geographically dispersed locations. IT-enabled network management reduces the cost of communication, helps to codify knowledge through software tools and databases, enables remote control, and facilitates exchange of tacit knowledge through audiovisual media.

The high cost and risk of developing IT has forced companies to search for lower-cost locations for R&D.

In essence, IT has fostered the development of leaner and more agile production and innovation networks that cut across firm boundaries and national borders. This has substantially reduced the friction of time and space not only for sales and production, but also for R&D and other innovative activities. IT-enabled network management has facilitated the exchange of knowledge among diverse knowledge communities at distant locations that work together on an innovation project.

It is now possible to create and connect teams of knowledge workers in distant locations, such as Silicon Valley, Seoul, Taiwan's Hsinchu Science Park, Beijing, Shanghai, Bangalore, Delhi, and Hyderabad. This is even possible for innovative activities that require complex knowledge. To the degree that the diversity of network players, locations, business models, and network arrangements is increasing, new opportunities for knowledge diffusion are emerging, enabling Asian network participants to enhance learning, absorptive capacity, and innovative capabilities.

A New Global Hierarchy of Innovation Hubs

The new geography of knowledge created by GINs is by no means a flatter world. A defining characteristic is a persistent inequality in the division of innovation tasks. A handful of established global centers of excellence in the United States, Japan, and the EU retain their dominance in science and high-impact intellectual property, and hence continue to shape technology roadmaps through radical and architectural innovations (see, e.g., European Patent Office 2007)

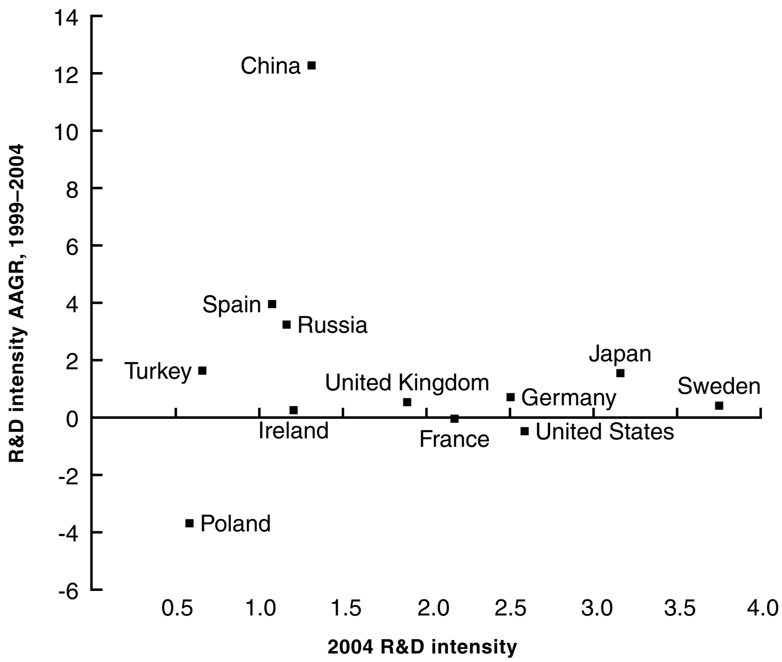
In 2002, for instance, all fifteen leading companies with the best record on patent citations were based in the United States, with nine of them in the IT sector (CHI/MIT 2003). The 700 largest R&D spenders (mostly large U.S. firms) account for 50 percent of the world's total R&D expenditures and more than two-thirds of the world's business R&D (UNCTAD 2005). And more than 80 percent of the 700 largest R&D spenders come from only five countries (the United States dominates, followed by Japan, Germany, the United Kingdom, and France).

Nevertheless, non-OECD countries account for a growing share of the world's R&D (OECD 2008b: 56). In 2005, the non-OECD countries accounted for 21.4 percent of global R&D expenditures (expressed in current U.S. dollars purchasing power parity), up from 17 percent four years earlier. China made by far the largest contribution, accounting for 55 percent of the non-OECD share. As shown in figure 2, China's R&D intensity (i.e., the ratio of R&D to gross domestic product, or GDP) has grown much faster than in the United States, Japan, or any European country. However, China's R&D intensity is still way behind that of the global leaders.

… non-OECD countries account for a growing share of the world's R&D

Probably the most telling indicator of the persistent high concentration of innovative capabilities is the unequal control over resources and decision making in standard-setting consortia in the IT industry (Ernst

Figure 2. R&D Intensity in 2004 and Annual Average Growth Rate (AAGR; of R&D Intensity, 1999–2004*)



Adapted from: Eurostat, "R&D expenditure in Europe," *Statistics in Focus*, European Communities, June. 2006.
* R&D intensity is R&D expenditure as a percentage of GDP.

2008b). In many of these consortia, standards are highly "impure public goods" that are used by incumbent industry leaders to block competitors and to deter new entrants.[32]

Clearly, GINs have dispersed innovative capabilities to new players, but overall this dispersion remains highly concentrated. For Asia, our data show that integration into these networks has created a handful of new, yet very diverse and intensely competing, innovation offshoring hubs.

GINs have dispersed innovative capabilities to new players, but this dispersion remains highly concentrated

Take chip design. Instead of the established global centers of excellence (such as Silicon Valley), there are now a handful of rapidly expanding new clusters emerging in Asia in places like Hsinchu, Taipei, and Tainan (in Taiwan); Shanghai, Suzhou, Hangzhou, Beijing, Shenzhen, and Xián (in

China); Seoul, Incheon, and Daedok Innopolis (in Korea); Bangalore, Noida, Chennai, Hyderabad, Mumbai, Pune, and Ahmedabad (in India); Penang and Kuala Lumpur (in Malaysia); and Singapore.

To capture the diversity of Asia's emerging innovation offshoring hubs, it is useful to distinguish between "home-base-exploiting" and "home-base-augmenting" overseas R&D labs (Kuemmerle 1996). "Home-base-exploiting" overseas R&D has been around for a long time. Its raison d'être is to adapt technology developed at the company's home base for commercialization in overseas markets. The key requirement for overseas R&D is the adaptation of products, services, and production processes to local needs and resource endowments.

By contrast, "home-base-augmenting" overseas R&D has become considerably more important since the 1990s. Its rational is external knowledge sourcing. "Home-base augmenting" taps into new sources of knowledge wherever they exist, and transfers that knowledge back to the home base. By combining these diverse technologies, "home-base augmenting" creates new products and processes (see, e.g., Granstrand, Patel, and Pavitt 1997). Hence, augmenting overseas R&D requires far more than adaptive engineering. It includes product development as well as applied and fundamental research.

The research conducted for this study identifies four types of Asian innovation offshoring hubs, determined by their focus on: 1) repetitive detailed engineering tasks; 2) contract R&D; 3) "home-base-exploiting" overseas R&D; and 4) "home-base-augmenting" R&D.

Hubs that focus on repetitive detailed engineering tasks are the least developed and are highly "footloose." Learning and domestic linkages in these locations are limited, and labs and projects can be closed down at short notice. Contract R&D hubs describe the pure-play version of innovation offshoring. The objective is to produce discrete modules of a global research project, and Asian network suppliers have little say in shaping the architecture and methodology of the project. The role of these hubs is confined to the provision of lower-cost skills, capabilities, and infrastructure. While dense information flows link these Asian hubs with R&D teams at headquarters and other affiliates, knowledge exchange remains tightly controlled and highly unequal.

Hubs that focus on "home-base-exploiting" overseas R&D typically include integrated product development (for local markets). The key requirements are capabilities that allow for a smooth and cost-effective adaptation of products, services, and production processes to local needs and resource endowments.

Finally, the highest stage, hubs that focus on "home-base-augmenting" R&D, is reserved for those R&D labs that are charged with a regional or global product mandate. Their main purpose is to utilize new knowledge that exists at this particular location and to combine diverse technologies to create new products and processes for regional or global markets. If these labs are part of MNCs, barriers to knowledge exchange tend to be lower, and these barriers may eventually give way to full-fledged mutual knowledge exchange.

Our research shows that Asian innovation offshoring hubs typically start out with a focus on repetitive detailed engineering tasks. Over time, these locations tend to graduate to a combination of contract R&D and "home-base-exploiting" overseas R&D, provided appropriate policies are in place to strengthen local capabilities.[33] However, there are also examples of (more) equal partnership arrangements that focus on "home-base-augmenting" R&D. These examples reflect the growing concern of global corporations to access localized knowledge and capabilities. Another motivation is to interact closely with the development of emerging alternative standards, like China's standards in mobile telecommunications, open source software, and digital consumer electronics (see, e.g., Kennedy, Suttmeier, and Jun 2008).

a new geography of knowledge … is shaped by intense competition between multiple and hierarchically ordered innovation hubs

Overall, the spread of GINs has created a new geography of knowledge that is shaped by intense competition between multiple and hierarchically ordered innovation hubs. Simplifying somewhat, it is useful to distinguish four types of innovation hubs:[34]

- global centers of excellence in the United States, Japan, and the EU;
- advanced locations (e.g., Israel, Ireland, Taiwan, and Korea)
- Catching-up locations (e.g., Beijing, the Yangtze River Delta, and the Pearl River Delta in China, and Bangalore, Chennai, Hyderabad, and Delhi in India)

- "New frontier" locations (e.g., lower-tier cities in China and India plus Romania, Armenia, Bulgaria, Vietnam, and others)

Global Centers of Excellence

The existing global centers of excellence continue to dominate, but they are now facing new challenges. The defining characteristics of these hubs are a broad knowledge base and access to basic and applied research capabilities that are combined with a sophisticated "innovation infrastructure"[35] and a fully integrated portfolio of soft complementary innovative capabilities. This allows firms in these locations to pursue technology leadership strategies, based on radical innovations and the development of mission-based complex technology systems.[36]

The existing global centers of excellence … are now facing new challenges.

These locations are now facing new challenges, in terms of lagging R&D productivity and contested risks of innovation. Another challenge is the drying up of funds (especially venture capital) for R&D as a result of the financial crisis. It is for these global centers of excellence that Tassey's concept of "the technology imperative" (2007) has been developed. To sustain technological leadership, "more comprehensive growth policies [need to be] implemented with considerable more resources and based on substantive policy analysis capabilities" (Tassey 2008: 2).[37]

Advanced Locations

These hubs have a history dating back to the late 1960s, when the offshoring of U.S. manufacturing activities in the electronics industry gave rise to the development of local engineering and product development capabilities (see, e.g., Tilton 1971, Ernst 1983, and Ernst and O'Connor 1992). Early integration of these locations into global production networks of MNCs has exposed local firms to sophisticated export markets. Network participation has multiplied conduits for knowledge transfers to local firms, broadening their scope for learning and capability development (Ernst and Kim 2002). This, in turn, has created new opportunities, pressures, and incentives for local network suppliers to upgrade their technological and management capabilities and the skill levels of workers.

In addition, government policies have played an important role in strengthening absorptive capacity, by investing in infrastructure and complementary support services and institutions, and by providing incentives for learning and industrial upgrading.

These advanced locations are now facing new challenges: they are "sandwiched" between the incumbent global centers of excellence and the rising catching-up locations.

Catching-up Locations

These hubs are the result of a second wave of offshoring, starting in the late 1980s, that gave rise to "global factories" for manufactured products (in China) and services (in India). As in the advanced locations, integration into global production networks provided a powerful catalyst for learning and capability formation.

However, in catching-up locations this process was compressed into an even shorter period than in the advanced locations. They were progressively integrated into GINs which has forced companies and governments to accelerate the speed of learning.

To avoid diminishing returns of network integration, firms in these locations now must increase R&D and the supply of well-educated and experienced knowledge workers. Intense competition for a limited talent pool from both global centers of excellence and advanced locations, and new competitive challenges from lower-cost new frontier locations are constraining such "upgrading-through-innovation" strategies.

"New Frontier" Locations

As catching-up locations are facing decreasing returns in terms of agglomeration diseconomies and localized wage inflation, especially for highly skilled and experienced knowledge workers, global corporations are relocating the lower end of their R&D activities to "new frontier" locations. In China, for instance, such locations are lower-tier cities like Xián or Chengdu or Chongqing. In India, lower-tier cities, some of them with a rich industrial heritage, include cities like Ahmadabad or Pune.

… corporations are relocating … R&D activities to "new frontier" locations.

The main attraction of these “new frontier” locations is an ample supply of low-cost, highly motivated, and trainable engineers and technicians who are willing to work long hours at low pay and in a highly-structured factory automation-type working environment. These locations, however, are constrained by gaps in infrastructure, weak regimes of intellectual property rights protection, widespread market imperfections, and limited exposure to modern U.S.-style management systems.

The Challenge for Asia: Will Network Integration Foster Innovation?

There is a broad consensus that integration into global networks of production and innovation has facilitated the catching-up of Asian firms as fast followers who compete on cost and speed to market. But how might progressive integration of Asian firms into these networks affect learning, capability formation, and innovation? Furthermore, is network integration a poisoned chalice for Asian firms, or will it reduce entrenched barriers to innovation?

The research clearly indicates that there is nothing automatic about these processes and that they cannot be left to market forces. To cope with market failures identified many years ago by Kenneth J. Arrow (1962), appropriate policies need to be in place to develop absorptive capacity and innovative capabilities, both at the firm level and across the industry.

Support policies for local firms will be required. And, as emphasized by Tassey (2007), substantial investments are needed in “human science and engineering capital” and “innovation infrastructure.” An important objective is to improve the efficiency of a nation’s innovation systems and to reduce the risks of innovation.

A Poisoned Chalice?

There are concerns that integration into global innovation networks 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.

The research behind this study shows that Asian emerging economies must surmount massive challenges before they can reap the benefits of deeper network integration. Foreign R&D centers often intensify competition for the limited domestic talent pool, giving rise to bouts of localized wage inflation for knowledge workers, and especially for experienced project managers. 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.[38] Furthermore, foreign R&D centers typically show limited interest in sharing knowledge with domestic firms and R&D labs.

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 foreign-owned 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 2005).

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 Asian 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, Asian firms may now face severe "IP barriers," as "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.).[39]

New Opportunities for Knowledge Diffusion and Learning?

Will global innovation networks also create new opportunities for knowledge diffusion and learning in Asia's innovation offshoring hubs? The research shows that foreign R&D centers can act as important catalysts for accelerated learning and capability development. Interviews with foreign affiliates of global corporations as well as with independent Asian network suppliers indicate that integration into global innovation networks can improve access to state-of-the-art innovation management practices, tools, ideas, and opportunities for innovation.[40]

A look at earlier research on knowledge diffusion through global production networks explains why this is so. Ernst and Kim (2002: 1417) find that global corporations that act as "network flagships" "transfer both explicit and tacit knowledge to local suppliers through formal and informal mechanisms. This is necessary to upgrade the local suppliers' technical and managerial skills so that they can meet the flagships' specifications." Furthermore, "once a network supplier successfully upgrades its capabilities, this creates an incentive for flagships to transfer more sophisticated knowledge, including engineering, product and process development" (ibid.: 1422).

… foreign R&D centers can act as important catalysts for accelerated learning …

This willingness to transfer more sophisticated knowledge reflects the increasingly demanding competitive requirements, especially in R&D-intensive sectors of the electronics industry, which 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.[41] Only those companies that succeed in bringing new products to the relevant markets ahead of their competitors will thrive. Of critical importance for competitive success is that a firm can build specialized capabilities quicker and at a lower cost than its competitors (Kogut and Zander 1993).

No firm, not even a global market leader like IBM, can mobilize internally all the diverse resources, capabilities, and bodies of knowledge that are necessary to fulfill this task. As a consequence, global firms increasingly "externalize" both the sources of knowledge and its use. 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 expecting new opportunities for knowledge diffusion and learning is that, for global firms, benefits from GINs are too important to neglect. These networks allow global firms to reduce the rising costs of R&D and to gain access to new sources of innovation. In addition, GINs help global firms to hedge against failures of internal R&D projects or against slippage in capacity expansion.

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

… for global firms, benefits from GINs are too important to neglect.

Fourth, the expansion of GINs has increased the diversity of network players, locations, business models, and network arrangements. As Ernst (2005a, 2005b) demonstrates, this expansion increases the challenge for effective network coordination, but it also creates new opportunities for knowledge diffusion, enabling Asian network participants to enhance learning, absorptive capacity, and innovative capabilities.

And fifth, global firms need GINs 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 United States.[42]

For many high-tech companies, competing for scarce global talent thus has become a major strategic concern. 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 emerging Asia's lower-cost labor markets. Over time, global firms realize that, in order to retain these knowledge workers, it is necessary to transfer exciting projects to the new locations in Asia that provide opportunities for learning and knowledge sharing.

All of this implies that innovation systems of global corporations are being opened to outsiders, at least in a few select areas. Of course, global corporations will continue to pursue countervailing IP barrier strategies, in order to minimize the leakage of knowledge. But the scope for such strategies may be gradually reduced, as knowledge sharing is the glue that keeps global innovation networks growing. Our research shows that the balance is shifting from IP barrier strategies to strategies that seek to "externalize IP" through global innovation networks. For Asian network suppliers, this creates new opportunities for learning and knowledge absorption.

Asian Innovation Strategies: A Stylized Model

To take advantage of these opportunities, considerable changes are required in Asia's innovation strategies, policies, and management approaches. As latecomers to innovation, Asian firms are confronted with substantial barriers. At the same time, being a latecomer also conveys important advantages, as it is possible to learn from the mistakes of earlier latecomers to innovation. Asia's emerging economies thus have to develop their own idiosyncratic approaches to innovation strategies, policies, and innovation management.

… latecomers to innovation [are] confronted with substantial barriers

Much of the debate has focused on the transition from catching-up to fast-follower strategies. Catching-up requires the mastery of capabilities that are necessary to implement, assimilate, and improve foreign technologies. This set of primarily operational capabilities makes it possible to enter a product market after growth has peaked and to do so as a low-cost producer. Fast-follower strategies, on the other hand, aim at entering a product market right at the beginning of its high growth stage. This requires a broader set of capabilities that now also includes certain aspects of innovation. However, the primary focus of innovation in fast-follower strategies is on organizational arrangements that make it possible to combine quick market response ("time compression"), flexible production, and systemic cost control across all stages of the value chain through supply chain and customer relations management.

Asia's leading exporting countries have all successfully made that transition. The question is: which model should Asia follow now?

Technology Leadership Is Not the Only Option

Research on innovation strategies in industrialized countries (see, e.g., OECD 2000) points to technology leadership strategies that focus on radical innovations that involve both the use of new component technology and changes in architectural design.[43] The objective is to become a prime mover of knowledge creation by setting global standards during product introduction. Radical innovations challenge established market leaders, since they destroy the usefulness of the leaders' capabilities. Radical innovations require the creation of new intellectual property rights, especially a broad portfolio of frequently cited "pioneer" patents connected with important inventions and discoveries.

In the electronics industry, for instance, competition centers on "essential" patents to the standard.[44] These patents allow the patent holder to cross-license them instead of paying high royalty rates for other patents. With increasing complexity of technologies, these patent thickets become denser. For instance, for the GSM (the European mobile communications standard) for second-generation mobile telecommunications systems, 140 essential patents were claimed by their respective patent holders (Bekkers, Duysters, and Verspagen 2002).

For the current third-generation mobile standards, the number of essential patents has substantially increased.[45] For example, W-CDMA (one of the three competing 3G standards) is protected by more than 2,000 patent families comprising more than 6,000 individual patents from some 50 companies and consortia (Davey 2006). At the same time, the number of standards required for a single mobile device has grown exponentially. Today's typical high-end mobile handset combines hundreds of standards, coming from dozens of standard-setting organizations, for camera, video, web browser, PDA, WiFi, Bluetooth, Linux, USB, and more.

All of this demonstrates the enormous power that essential patents convey in the electronics industry as a weapon for entry deterrence strategies. Nevertheless, this privileged position only lasts as long as the standard is worthy. In telecommunications, the standards have a short life cycle. In addition, barriers to entry for new entrants are extremely prohibitive.

For Asian firms, attempts to compete head-on with global technology leaders necessitate a massive upgrading of absorptive capacity as well as innovative capabilities. To become a technology leader, Asian firms would need to have access to a broad base of applied and basic research. To develop such a broad research base takes time. It also requires very deep pockets to finance the massive increase of R&D. This in turn necessitates high profit margins based on premium pricing.

Most important, technology leadership strategies are extremely risky, and market prospects are highly uncertain. The new products may reflect ingenious radical innovations, yet this does not guarantee that customers are willing to pay for these innovations. In fact, the more complex the technology, the more difficult the resultant products are to use, and the more they are prone to breakdowns due to unproved technology.

… technology leadership strategies are extremely risky …

In Asia (outside of Japan), only a very few companies can master this game. But even those few are sometimes forced to stretch their resources to the limits. An example is Taiwan Semiconductor Manufacturing Corporation (TSMC), the world's leading IC foundry. Its success was built on pursuing a technology leadership strategy in IC process technology. This enabled TSMC to charge premium prices. But sustaining process technology leadership comes at an extremely high cost and risk.[46] And staying at the frontier of process technology requires dense interaction with top scientists and engineers who work at the frontier of basic and applied research in a broad range of disciplines.

As a result, TSMC had to invest in a broad range of global innovation networks with leading R&D partners, including leading labs at Berkeley, MIT, and Stanford, and the Inter-University Microelectronics Center in Louvain, Belgium. It also established close partnerships with the IC process development cluster in Crolles, close to Grenoble, with vendors of electronic design automation tools and test equipment, and with key customers. The cost of establishing and sustaining such networks is formidable and exceeds the resources of most Asian companies.

To move ahead with technology leadership strategies requires concerted industry-level upgrading efforts by government and industry, along the lines described by Tassey (2007). Such efforts are needed to reduce the very substantial barriers that individual firms face when they try to move to technology leadership strategies. Significant policy initiatives are under way in China and India, as well as in Korea, Taiwan, Singapore, and Malaysia.[47] The question is how quickly these initiatives will enable firms to develop commercially successful innovations.

But even then, the risks are high. This implies that an exclusive focus on technology leadership strategies is unlikely to support a broad-based upgrading through innovation strategy.

Technology Diversification as a Complementary Option

Technology diversification can serve as a complementary and arguably less costly option (Ernst 2005c). Defined as "the expansion of a company's or a product's technology base into a broader range of technology areas" (Granstrand 1998: 472), technology diversification focuses on products that draw "on several ... crucial technologies which do not have to be new to the world or difficult to acquire" (Granstrand and Sjoelander 1990: 37). Technology diversification requires strong research capabilities, but it is much more focused than "technology leadership" on applied research that feeds directly into product development.[48]

Technology diversification can serve as a complementary and arguably less costly option

For Asian emerging economies, technology diversification promises several advantages. It generates technology-related economies of scope by recombining (mostly known) component and process technologies. Second, technology diversification can also build on Asia's existing strengths in process development, prototyping, and electronic design, as well as on recent progress in the development of integrated solutions capabilities. Third, Asian firms can build on their accumulated capabilities to implement, assimilate, and improve foreign technologies, as technology diversification often involves the exchange of knowledge with foreign parties.

A final, critical advantage of technology diversification is that by focusing on architectural innovations, Asian firms can extract greater benefits from deeper forms of integration into global innovation networks. As discussed above, architectural innovations use existing component technology but change the way components are designed to work together, hence breaking new ground in product development.

Capability requirements are demanding, but they are within reach of Asian companies. Of critical importance is a capacity to develop products and services that are less overengineered and expensive than those of global market leaders and that address "effective customer needs" that incumbent global market leaders have neglected. And barriers to implement that new architecture are limited. In fact, Asian firms do not need to develop the necessary components, nor do they have to change them. Integration into global innovation networks has broadened the scope for Asian firms to procure the relevant component technology from specialized suppliers. Asian firms also might engage in collaborative development of some of these components.

This collaboration, of course, requires a substantial improvement in the approach of Asian firms to the protection of intellectual property rights. Clearly, such a fundamental change will take time, but there is no doubt that a transition from copying foreign technology to developing new indigenous technology is taking shape. The research shows that leading Asian firms are now making serious efforts to catch up in the mastery of these most critical innovative capabilities. For examples, see the box below.

Box 1. Examples of Technology Diversification through Architectural Innovations

Huawei's Integrated IP Service Platform ME60

In June 2005, Huawei, China's leading telecommunications equipment vendor, introduced the first integrated multiservice platform on the market that enables telecommunications operators to substantially improve the quality of service and the security of their Internet protocol (IP) services at a reduced cost of operation. Current IP networks do not offer the security and quality of service that operators want, while traditional networks are incapable of supporting bandwidth-hungry multimedia services such as Internet protocol television. To improve service, quality, and security, these products need to be aggregated and run over a common IP core.[49]

The ME60 is the "Swiss army knife" that enables operators to aggregate multiple services from various networks into one IP core and that improves the operators' real-time control over these services. Technically, this system is quite an achievement. As a 10-gigabit multiservice control gateway,[50] the ME60 is an edge router that sits between the IP core and the access network (which may be fixed or mobile). The ME60 can deliver, at a reasonable cost of operation, tailor-made products in response to the specific needs of telecommunications service providers. Such integrated and flexible integrated solutions are not widely offered in the network equipment industry, where incumbent industry leaders typically provide standard solutions. These high R&D costs necessitate a business model that seeks to reap economies of scale through the mass manufacturing of standard and fairly inflexible solutions.

Being a latecomer, Huawei decided to follow a different business model that focuses on providing lower-cost integrated solutions that are adaptable to the specific needs of telecom operators, especially in emerging markets that need to reduce the life cycle costs of operating these systems. The company was able to do so by recombining existing component technologies in new ways so that it could provide an adjustable and integrated lower-cost IP service platform. A distinguishing feature of the ME60 is its high level of integration through a single software system. This makes it possible to integrate the capabilities currently separated in different network parts like broadband remote access servers and firewalls that until now had no communication standards.

Taiwan's Architectural Innovators

Taiwan's leading electronics firms have made serious efforts to develop technology diversification strategies through architectural innovations. For instance, HTC, Taiwan's leading own-brand handset vendor, has developed highly successful commercial smart handsets, and it uses an open-source platform for its partners to collaborate. And Asus, among other interesting projects, has used a loosely coupled global product development network to bring to market at record speed the first commercially viable ultra–low cost laptop.

Policy Implications

There is no doubt that the innovative capabilities of Asian firms continue to lag substantially behind those of global industry leaders. Reducing the gap will take time.

Asia's emerging knowledge economies thus face a strategic dilemma. If they choose to compete as lower-cost R&D contractors, this will result in a "commodity price trap," squeezing their profit margins and hence funds available to invest in innovation. There is not much choice

Asia's emerging knowledge economies … face a strategic dilemma

but to pursue "upgrading-through-innovation" strategies. Asian firms need to create unique products and solutions, addressing user and social needs that global firms have neglected. However, deeply entrenched structural weaknesses constrain the push for innovation.

The challenge for policymakers is to foster integrated solutions capabilities on an industry-wide level so that individual firms can access these capabilities without being saddled with the extremely high cost of developing them in-house.

Reaping the benefits of integration into GINs requires the active involvement of the state—local, regional, and central government agencies—as well as a variety of intermediate institutions (Ernst 2005c). 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 the old policies cope with the conflicting needs of multiple, and increasingly vocal, domestic actors. In addition, command-economy-type industrial policies are unable to deal with the high uncertainty and rapid changes in technology and markets that are typical for the new geography of knowledge.

Reaping the benefits of integration into GINs requires the active involvement of the state

In short, to facilitate a continuous upgrading of local innovative capabilities through participation in GINs, it is necessary to have new policy approaches that:

- strengthen the state's steering and coordination capacity;
- provide public goods in critical bottleneck areas (infrastructure, scarce skills, training, and education);
- facilitate access to and diffusion of knowledge and balance this with the need to protect intellectual property rights;[51]

- encourage overseas investment of leading local companies in order 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; and
- 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: 377). Future research needs to explore whether the experience of the electronics industry is relevant to other industries.

Conclusions

The geography of knowledge is experiencing fundamental transformations, culminating in the spread of GINs. These networks are real, and not just something nascent that can be expected in the future. This monograph documents that Asia's role in these networks is increasing (albeit from a low level), and that the resurgence of China and India as global economic powers plays an important role.

The systemic nature of the forces that are driving and enabling the geographical dispersion of innovation networks indicates that this is a lasting change in the geography of knowledge. As a result, technology-based competition has intensified, brutally exposing structural deficiencies of current learning and innovation strategies at the firm level and technology policy at the industry level.

Drawing on a unique database of GINs in the electronics industry, this study has explored how integration of Asian firms into GINs affects learning, capability formation, and innovation. It demonstrates that integration into these networks creates new opportunities for policies and corporate strategies in Asia to move beyond the "global factory" model to a strategy of industrial upgrading through innovation.

But the new geography of knowledge also poses very demanding challenges for Asia. The result is not a flatter world. Instead, integration into GINs has dispersed innovative capabilities to new players, but overall this dispersion remains highly concentrated in a handful of new, yet very diverse and intensely competing, innovation offshoring hubs in Asia.

As the diversity of network players, locations, business models, and network arrangements is increasing, new opportunities for knowledge diffusion are being created enabling Asian network participants to enhance learning, absorptive capacity, and innovative capabilities.

Finally, this study provides new insights on a critical question that is at the center of Asia's industrial policy debates: is network integration a poisoned chalice for Asian firms, or will it reduce entrenched barriers to innovation? The answer is that nothing about these processes is automatic. While integration into global networks of production and innovation has facilitated the catching-up of Asian firms as fast followers, it now may become a mixed blessing, unless Asian governments establish appropriate policies to develop absorptive capacity and innovative capabilities both at the firm level and across the industry.

Specifically, the study provides evidence for three propositions: 1) "absorptive capacity" is critical for attempts to develop and upgrade innovative capabilities; 2) Asian firms now must increase R&D to avoid diminishing returns of network integration; and 3) integration into diverse networks of production and innovation provide new opportunities for Asian emerging economies to pursue "technology diversification" as a complementary option to "technology leadership" strategies.

Future research needs to address the potentially game-changing impact of the current breakdown of the financial system and the resultant collapse of international trade and investment. These are not normal times. There is no doubt that the crisis is changing the rules of the game for all actors in the global economy. Hence, "business as usual" is no longer an option which is certainly the case for the dynamics of GINS and Asia's role in these networks.

Future research needs to address the impact of the collapse of international trade and investment.

There are now clear signs that Asia's prospects for investment and employment are grim and that demand and GDP growth will slow down significantly. It is unclear at this stage, however, how the crisis will affect Asia's innovative capacity and its response to the emerging new geography of knowledge. Future research thus needs to explore whether the crisis will facilitate or disrupt Asia's integration into global networks of production and innovation.

Endnotes

1. According to the U.S. 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: IV-36).
2. For instance, in a study on the globalization of innovation in the semiconductor industry, David Mowery and his coauthors emphasize that the "imperfect proxies" that we have to study the international location of innovation provide a picture of a "surprisingly low level of globalization" (Macher, Mowery, and Inin 2007: 1–2). Similar caveats are expressed by Catherine Mann, who has used sophisticated econometric analysis to examine U.S. technology trade data and to explore how U.S. parents fare relative to their foreign affiliates on R&D expenditures, R&D intensity, and patent grants (Mann 2006). Both Mowery and Mann emphasize that surveys of companies and detailed case studies are necessary to collect data that are sufficiently disaggregated and current. The GIN database, generated at the East-West Center, seeks to contribute to such a research agenda.
3. A follow-up paper, "Will the Crisis Facilitate or Disrupt Asia's Integration into Global Networks of Production and Innovation?" (Ernst, East-West Working Papers, forthcoming) will discuss the impact of the global crisis.
4. China and India are the most prominent examples, but the list of new locations includes both large countries like Russia, Brazil, Argentina, Mexico, South Africa, and (possibly) Vietnam, and many smaller countries, such as Korea, Taiwan, Malaysia, Singapore, Israel, the Gulf states, Poland, the Czech Republic, Hungary, and the Baltic states.
5. The metaphor of a "flat world" was fashionable before the global crisis (see, e.g., Friedman 2005), but now we know that spikes and inequalities are persistent and growing.
6. On GPNs, see Henderson et al. 2002 and Ernst 2002a, 2002b.

7. In his *Business Cycles* (1939: 84), Schumpeter pushes this distinction to the extreme, arguing that "innovation is possible without anything we should identify as invention, and invention does not necessarily induce innovation."

8. This broad definition is in line with Peter Drucker's classic statement, "The test of an innovation, after all, lies not in its novelty, its scientific content, or its cleverness. It lies in its success in the marketplace" (Drucker 1985: viii).

9. The boundaries between these four types of innovation are fluid. For instance, incremental and radical innovations are about the extent of changes caused by innovation, while modular and architectural innovations are about where the change is happening. They could therefore overlap.

10. According to China's Ministry of Information Industry, Huawei is now one of the three largest domestic Chinese software enterprises (together with ZTE and Haier).

11. Henderson and Clark (1990) use the decline of Xerox and RCA to illustrate the destructive power of architectural innovations.

12. A more recent example of an architectural innovation is Huawei's development of a new integrated IP service platform ME 60, which is discussed in the section "Technology Leadership Is Not the Only Option."

13. See the discussion in "The Challenge for Asia," below.

14. Important contributions include Lall 1992; Ernst and O'Connor 1992; Hobday 1995; Ernst, Ganiatsos, and Mytelka 1998; Jefferson and Kaifeng 2004; and Ernst 2005c.

15. This taxonomy, which suggested a sequential ordering of priorities for capability formation, was largely confirmed in that study's comparative analysis of how electronics and textile firms have developed their capabilities in Taiwan, Korea, Thailand, Indonesia, and Vietnam.

16. Important examples are the OECD Oslo Manual (OECD and Eurostat 2005), the Science, Technology and Innovation in Europe series (Eurostat 2008), and the final report of the "Innovation Vital Signs Project," prepared for the Technology Administration of the U.S. Department of Commerce (ASTRA 2007).

17. There are now attempts to improve the quality of collected data on the international dimension of innovation. In the United States, the Department of Commerce has established an Advisory Committee on "Measuring Innovation in the 21st Century." One notable initiative is that, in July 2003, the National Science Foundation, the Bureau of Economic Analysis, and the U.S. Census Bureau established a data-sharing and data-linkage project related to the globalization of industrial R&D. But so far the only result is that a feasibility study has established that the data reported by the different agencies are comparable and could be linked. Similar attempts by the European Commission are still at a very preliminary stage (as reported in ProInno Europe 2007).

18. For instance, a methodologically highly sophisticated study of U.S. technology trade data finds a fairly constant U.S. trade surplus until 2004 (Mann 2006). The study also shows that U.S. parents fare significantly better than their foreign affiliates on R&D expenditure, R&D intensity, and patent grants.

19. The UNCTAD sample consists of the first 300 firms of the R&D scoreboard of the 700 top worldwide R&D spenders, published by the UK Department of Trade and Industry.
20. Future publications are expected to apply econometric methods to some of the main findings of the database.
21. See the discussion of Asian innovation offshoring hubs in "A New Global Hierarchy of Innovation Hubs," below.
22. In chip design, these tasks include, for example, reverifying the design, chip layout, running manufacturability tests, and performing product engineering (Ernst 2005a).
23. The following is based on company interviews. Wherever possible, the information provided in these interviews was cross-checked with information from other sources within and outside the companies. However, an important constraint to data collection on this important issue is the "Fair Disclosure" regulation. As discussed in Ernst (2006: 30), this regulation stipulates that corporations must release market-sensitive information to all investors at the same time. It also imposes heavy fines if information leaks out to other people. Companies are therefore reluctant to share information with academic researchers. This regulation makes it difficult to evaluate claims made by individual companies with regard to specific R&D projects.
24. http://dqindia.ciol.commakesections.asp/07062104.asp, accessed November 19, 2008.
25. But, as Ron Wilson (2008) persuasively argues, this may change over time. Progressive design offshoring to Asia will lead to a separation of conceptualization, that is, defining the architecture of a chip (which remains in the United States) from actual design implementation (in Asia). "If US companies allow themselves to become architectural firms without a solid grounding in design, verification, manufacturing, and test, they will run a major risk of becoming uncompetitive as architects as well."
26. Future research needs to explore whether the growth of transpacific mini-GINs will be a sustainable development or whether the global crisis of 2008 will derail or slow down this process.
27. These ODMs either implement a detailed set of design specifications provided by the global brand leader or they provide their proprietary integrated "turnkey" solution to basic performance parameters requested by the global brand leaders. Taiwanese ODM service providers now account for 95 percent of the global notebook market, with three firms (Quanta, Compal, and Wistron) accounting for 71 percent. It is important to emphasize that tier-three suppliers, especially for power supply (Delta and Lite-On) and connectors (HonHai), are highly profitable and are investing heavily in the development of their innovative capabilities.
28. The global recession since 2008 has further increased the importance of the China market.
29. According to the National Science Board (2008), 64 percent of China's 23,446 PhD degrees in 2004 are in science and engineering. And between 1995 and 2003, first-year entrants in science and engineering PhD programs in China increased sixfold, from 8,139 to 48,740.

30. Additional powerful enabling factors are the progressive globalization of IP protection (through the Agreement on Trade Related Aspects of Intellectual Property Rights, or TRIPS, and TRIPS-Plus agreements) and standards (through formal but especially through informal standard-setting bodies). See Ernst 2008b.

31. Liberalization includes four main elements: trade, capital flows, foreign direct investment (FDI), and privatization. These different forms of liberalization hang together. Trade liberalization typically sparks an expansion of trade and FDI, which in turn increases demand for cross-border capital flows. This increases pressure for liberalization of capital markets, which forces more countries to open their capital accounts. It also opens up incentives to develop and diversify capital markets, which lowers the cost of capital. In turn, this encourages liberalization of FDI and privatization tournaments.

32. A recent study of the 250 major standard consortia in the electronics industry shows that "about 50–100 major players, plus governments [in the United States, the EU, and Japan] determine what [these consortia] do, and more importantly, how they do it" (79 Brinkburn 2008). The major players include the usual suspects, with the top ten leaders being IBM, Microsoft, Fujitsu, Intel, Hewlett-Packard, Hitachi, Sun Microsystems, Nokia, Ericsson, and Texas Instruments. Of the fifty major players in standardization organizations that deal with information and communication technology, twenty-five are from the United States, twelve from the EU, and eight from Japan. Only five companies from emerging countries (all from Asia) are consortia members. These are (listed in declining number of members): Samsung, Huawei, LG, Lenovo, and ZTE. In addition, the study shows that of the 753 corporate memberships in major ICT standard consortia, these five companies from China and Korea account for fifty-one memberships, a share that is smaller than 7 percent.

33. This finding is confirmed by recent research on China (e.g., von Zedwitz 2004; Gassmann and Han 2004; Li and Zhong 2003) and Taiwan (e.g., Chen Shin-Horng 2006; Chang, Shih, and Wei 2006).

34. The main purpose of this taxonomy is to highlight the hierarchical, decidedly nonflat nature of the new geography of knowledge. As argued in "The Challenge for Asia," below, upgrading from lower-tier to the higher types of innovation hubs is by no means an automatic process.

35. "Innovation infrastructure" is defined as a "ubiquitous set of infratechnologies (measurement and test methods, process control techniques, science and engineering data, data formats and interface protocols) which often become industry standards" (Tassey 2008: 11). Its main function is to lower entry barriers, reduce risks, and improve productivity.

36. The term "mission-based complex technology systems" is a shorthand that is used for large, mostly government-supported research projects in the areas of space, defense, energy, environment, climate, and health.

37. Tassey (2007: 86) acknowledges that these policies "will have to be accomplished in the context of ongoing globalization of corporate strategies." The new doctrine thus differs from "techno-nationalism," which, as aptly described by Ostry and Nelson (1995), treats science and technology primarily as weapons to improve national balance of payments.

38. Examples are attempts by IBM and Accenture to copy the successful business model of Indian IT service providers like Tata Consulting Services or Infosys.

39. The other side of the coin, of course, is that this is forcing Asian countries to boost IP protection and the development of their own innovations.

40. This is in line with recent studies in 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) shows that the R&D intensity of foreign-owned affiliates in Taiwan's manufacturing industry has increased from 1.5 percent in 2002 to 1.9 percent in 2003. Chen argues that foreign-owned subsidiaries with high export intensity and which rely on Taiwanese original equipment manufacturing/original design manufacturing 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."

41. On average, a new product generation is introduced every nine months, and for high-end handsets the cycle can be as short as six months, almost as short as for fashion-intensive garments.

42. However, aging is also expected to become a serious challenge after 2010 for Asia's leading exporting countries (with the exception of India).

43. See "A Taxonomy," above.

44. An "essential" patent is necessary to produce any product that meets the relevant interfaces defined in the standard. It can cover either general system architecture or specific details.

45. For details, see Ernst 2008b.

46. Establishing a state-of-the-art factory ("fab") that is capable of producing chips from 12-inch wafers with 90-nanometer process technology requires an investment of up to $4.5 billion.

47. In China, for instance, the Medium- and Long-Term National Science and Technology Plan, introduced in 2006 after heated debates among scientists, engineers, policymakers, and industry executives, has identified three major objectives: 1) to utilize science and technology to support and lead future economic growth, especially in energy, water and resource utilization, environment protection, and public health; 2) to "leapfrog" to research frontiers in key scientific disciplines (including bio- and nanotechnology); and 3) to focus on "independent innovation" to redress China's weak record of innovation in commercial technologies (i.e., weak firm-level innovative capabilities). See OECD 2008c.

48. Empirical research on Japanese, U.S., and Swedish companies has demonstrated that technology diversification plays a more important role than technology substitution, as seen from the larger number of old technologies in a current product generation compared to the number of obsolete technologies (see, e.g., Granstrand, Patel, and Pavitt 1997).

49. The internet protocol core, also sometimes called the backbone, is the primary path of Internet network traffic. It connects smaller segments of a network and has a high concentration of traffic.

50. A gateway is the entrance to another network. The gateway allows equipment with different protocols to communicate with one another.

51. For a discussion of the implications for standards and innovation policies, see Ernst 2008b.

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About This Issue

Debates about globalization are focused on offshore outsourcing of manufacturing and services. This approach, however, neglects an important change in the geography of knowledge––the emergence of global innovation networks (GINs) that integrate dispersed engineering, product development, and research activities across geographic borders.

This new form of globalization poses new challenges and opportunities for research on international economics, economic geography, and international relations and for developing new policy responses. Written by a leading expert, this monograph draws on a unique database of GINs in the electronics industry to explore their drivers and impacts and how integration of Asian firms into these networks affects their learning, capability formation, and innovation. The study shows a rapid expansion of these networks, driven by a relentless slicing and dicing ("modularization") of engineering, development, and research. Asia's role in these networks, quite minor until recently, is increasing. The resurgence of China and India as markets and production sites plays an important role in that increase.

However, the new geography of knowledge is not a flatter world where technical change and liberalization rapidly spread the benefits of globalization. Instead, the offshoring of R&D through GINs creates a handful of new—yet very diverse and intensely competing—innovation offshoring hubs in Asia. A new global hierarchy of innovation hubs juxtaposes global centers of excellence in the United States, Japan, and the European Union and a handful of new—yet very diverse and intensely competing—innovation offshoring hubs in Asia. While integration into GINs has facilitated Asian firms catching up with those in the West, this may become a mixed blessing unless Asian governments can establish appropriate policies for developing absorptive capacity and innovative capabilities both at the firm level and across the industry.

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