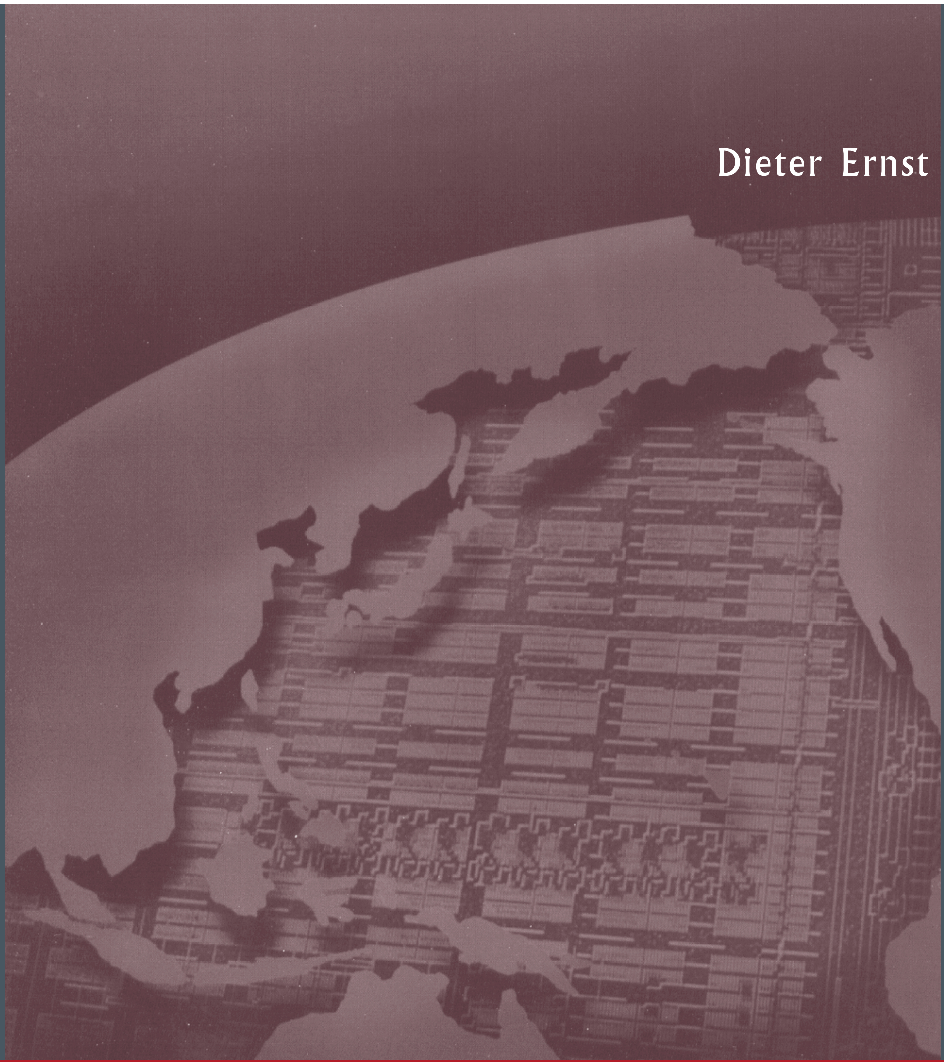
Innovation Offshoring

Asia's Emerging Role in Global Innovation Networks

Dieter Ernst



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Publication Sales Office
East-West Center
1601 East-West Road
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CONTENTS

Dieter Ernst *is a senior fellow in the Economics Study Area of the East-West Center Research Program. He has done extensive research and writing about offshore outsourcing through global production and innovation networks, global markets for knowledge workers, and the implications of offshore outsourcing for industrial and technology policies.*

SUMMARY

Most analysts agree that critical ingredients for economic growth, competitiveness, and welfare in the United States have been policies that encourage strong investment in research and development (R&D) and innovation. In addition, there is a general perception that technological innovation must be based in the United States to remain a pillar of the American economy.

Over the past decade, however, the rise of Asia as an important location for "innovation offshoring" has begun to challenge these familiar notions and the sense of complacency they have engendered. Based on original research, the paper demonstrates that innovation offshoring is driven by profound changes in corporate innovation management as well as by the globalization of markets for technology and knowledge workers. U.S. companies are at the forefront of this trend, experimenting with new approaches to the management of global innovation networks. But Asian governments and firms are playing an increasingly active role as promoters and new sources of innovation.

Innovation offshoring has created a competitive challenge of historic proportions for the United States. There are concerns that innovation offshoring may extend the "hollowing-out" of the U.S. economy well beyond manufacturing to include research and development, the most precious source of its economic growth. Some fear that a loss of knowledge worker jobs to Asia may erode the nation's innovative capabilities. These concerns may feed into increasing technological protectionism.

But the simple metaphor—Asia's rise versus America's decline—is clearly misleading. This paper demonstrates that innovation offshoring does not have to be a zero-sum game. It also creates new opportunities for the United States and for U.S.-Asia economic relations. Stronger innovation capabilities in Asia create new markets for U.S. firms. More importantly, the globalization of markets for technology and knowledge workers and the expansion of knowledge diffusion through global innovation networks create a powerful catalyst for renewed efforts at home to strengthen the U.S. innovation system. In short, more innovation in Asia does not mean less innovation in the United States—Asia's progress may well enhance our capacity to produce significant innovations and market-defining standards.

The United States needs a new national strategy to cope with the opportunities and challenges posed by innovation offshoring. This report recommends that such a strategy include the following elements:

1. Improve access to and collection of innovation-related data to inform the national policy debate;

2. Address "home-made" causes of innovation offshoring by sustaining and building upon existing strengths of the U.S. innovation system;

3. Support corporate innovation by (1) providing tax incentives to spur early-stage investments in innovative start-ups and (2) reforming the U.S. patent system so it is more accessible to smaller inventors and innovators; and

4. Upgrade the U.S. talent pool of knowledge workers by (1) providing incentives to study science and engineering; (2) encouraging the development of management, interpretive, cross-cultural, and other "soft" capabilities; and (3) encouraging immigration of highly skilled workers.

Introduction

Most analysts agree that critical ingredients for economic growth, competitiveness, and welfare in the United States have been policies that encourage strong investment in research and development (R&D) and innovation. In addition, there is a general perception that technological innovation must be based in the United States to remain a pillar of the American economy.

Over the past decade, however, the rise of Asia* as an important location for "innovation offshoring" has begun to challenge these familiar notions and the sense of complacency they have engendered. U.S. companies are at the forefront of this trend, experimenting with new approaches to the management of global innovation networks. But Asian governments and firms are playing an increasingly active role as promoters and new sources of innovation.

Asian governments and firms are increasingly active as promoters and new sources of innovation

Innovation offshoring is therefore likely to accelerate. It is driven by fundamental changes in corporate innovation management as well as the globalization of markets for technology and knowledge workers.† Innovation offshoring thus creates a whole new set of challenges—and opportunities—for the United States in its relations with the Asia Pacific region.

The main drivers of this change are global corporations, primarily from the United States. They are increasing their overseas investment in R&D while seeking to integrate geographically dispersed innovation clusters into global networks of production, engineering, development, and research. This trend has added a new dimension to the traditional notion of global production networks (GPNs), transforming them into global innovation networks (GINs).

Much of the action now is in Asia, owing to competition for Asia's lower-cost knowledge workers, the region's large and increasingly sophisticated markets, and policies aimed at developing the region's innovative capabilities. U.S. companies "offshore" stages of innovation to Asian affiliates to tap into the lower-cost talent pool and innovative capabilities of the region's leading export economies. This has led to the establishment of *intra-firm* GINs. But U.S. firms also "outsource" some stages of innovation to specialized Asian suppliers as part of complex *inter-firm* GINs.

It is time to correct earlier claims that only low-level service jobs will move offshore[1] and that there is "little evidence" of a major push by American companies to set up research operations in the developing world.[2] Innovation offshoring goes far beyond the migration of relatively routine services like call centers, software programming, and business process support —the subject of current public debates on "outsourcing." Beyond adaptation, innovation offshoring in Asia now also encompasses the creation of new products and processes.

This opens new opportunities for Asia to move beyond its traditional role as the primary "global factory" for manufactures, software, and business services. But it also raises tough policy and strategic challenges. Across the region, governments and domestic firms are all searching for strategies that would enable them to benefit from integration into GINs.

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* Throughout this paper, "Asia" excludes Japan. Unless indicated otherwise, data are from the author's research.

† "Knowledge workers," a term originally coined by the late Peter Drucker, is defined to include science and engineering personnel. This term also refers to managers and specialized professionals in areas such as marketing, legal services, and industrial design who provide essential support services to research, development, and engineering.

China and India have clearly been at the forefront, but equally important are developments in South Korea, Taiwan, Singapore, and Malaysia.

In the United States, there are concerns that innovation offshoring may extend the "hollowing-out" of the economy well beyond manufacturing to include R&D, the most precious source of its economic growth. It is feared that a loss of knowledge worker jobs to Asia may erode the nation's innovative capabilities. These fears may well feed into increasing technological protectionism.

But innovation offshoring does not need to be a zero-sum game. It also creates new opportunities for the United States and for U.S.-Asia economic relations. Stronger innovation capabilities in Asia create new markets for U.S. firms. More importantly, as markets for technology and knowledge workers become globalized and as knowledge diffusion expands through GINs, this creates a powerful catalyst for renewed efforts at home to strengthen the U.S. innovation system. In short, more innovation in Asia does not mean less innovation in the United States—Asia's progress may well enhance our capacity to produce significant innovations and market-defining standards.

In short, both the United States and Asia need alternative strategies and policies to cope with these new opportunities and challenges. Unfortunately, we still know relatively little about the forces that are driving or constraining the offshoring and outsourcing of innovation to Asia. We know even less about possible impacts and effective policy responses.

This paper explores how innovation offshoring is likely to affect U.S.-Asia economic relations and discusses policy responses. The analysis focuses on the electronics industry, which dominates U.S.-Asia trade and direct investment, using chip design as a test case to examine the forces driving the offshoring of innovation.

- Part I reviews the foundations of Asia's rise as an important location for innovation offshoring, highlighting achievements and policies to cope with the decreasing returns to the export-led global factory model.
- Part II analyzes the forces behind the growing organizational and geographical mobility of innovation within GINs and explores what they imply for innovation offshoring.
- Part III summarizes findings of the case study, examining the growing complexity of design stages and capabilities performed in Asia and the forces that are driving the offshoring of chip design.
- Part IV offers generic policy suggestions for the United States to ensure that benefits of innovation offshoring are not countered by a creeping longer-term hollowing-out of the nation's talent pool and its production and innovation system.

The Rise of Asia

The emergence of Asia as an important location for innovation offshoring signals a profound shift in the center of gravity in the global economy. It owes much to the region's success as the primary global factory in industries as diverse as textiles, footwear, agro-industries, electronics, steel, cars, machine tools, software, and IT-enabled business services.

THE GLOBAL FACTORY

The integration of Asian firms into GPNs provides a fascinating example of how linkages with foreign firms have stimulated industrial development.[3] Through GPNs, Asian firms have been able to tap into the world's leading markets, especially in the United States, and compensate for the initially small size of their domestic markets. Network participation also has provided access to leading-edge technology and best-practice management approaches. This, in turn, has created new opportunities, pressures, and incentives for Asian network suppliers to upgrade their technological and management capabilities and the skill levels of workers.[4]

Aggressive support policies of Asian governments enabled local firms to take advantage of opportunities to improve their positions in these networks. The result is one of the most impressive success stories of Third World economic development. During the first years of the new century, the region's rate of growth in gross domestic product (GDP), trade, and inward foreign direct investment (FDI) has surpassed even the impressive pace it achieved during the 1980s and 1990s. Asia also has become an increasingly sophisticated market for an even wider array of goods and services.

China is at the center of Asia's accelerated rise in the global economy. Estimates for 2006 suggest that China will overtake the United Kingdom to become the fourth-largest economy at market prices.[5] When differing price levels between countries are taken into account, China already ranks second in terms of its GDP at purchasing power parity prices. Based on its swelling trade surplus, China is projected to accumulate more than $1,000 billion in foreign exchange, a total that would surpass Japan's projected reserves. China's rising economic power is reflected in its refusal to succumb to U.S. pressure for a quick revaluation of the *renminbi* against the dollar. There is also speculation that China is likely to reduce its purchases of U.S. dollar-denominated assets.

Some skeptics doubt China's rise in the global economy.[6] They point out that China's share of global GDP in 2005 stood at 4.9 percent, while China's exports accounted for 7.3 percent of global exports. "China is still a tiny cog in the global wheel," they conclude.

The fallacy of using such aggregate data becomes evident when one looks at specific sectors. No other industry reflects Asia's rise as well as the electronics industry. Asia's five leading exporting countries (China, South Korea, Taiwan, Singapore, and Malaysia) today account for more than one-fourth of world electronics manufacturing output. These five countries occupy leading positions in global markets for digital consumer electronics, computers, and mobile devices, as well as for high-precision components, such as semiconductors and displays.

In 2004 China surpassed the U.S. as the world's largest exporter of electronic products

In the semiconductor industry, for instance, roughly 70 percent of output is now based in Asia. In addition, India has firmly established itself as a global export production base for software and IT-enabled business services and is emerging as the next frontier for offshore manufacturing in sectors as diverse as car components, electronic components, and pharmaceuticals.

This process has culminated in China's emergence as the dominant global factory location. Since 2004, China has surpassed the United States as the world's largest exporter of electronic products—a dramatic increase from its 10th place position in 2000. The rapid improvement in the country's export portfolio has been particularly noteworthy. Digital consumer electronics and mobile telecommunications equipment have increased relative to commodity-type appliances. In addition, PCs and electronic components have become China's second-biggest electronics export item.

At the same time, China's emergence as the second-largest electronics importer (up from seventh place in 2000), indicates the growing importance of Asia's rapidly growing and increasingly sophisticated markets for communications, computing, and digital consumer equipment, and for the electronic components (especially semiconductors) required by Asia's global electronics factories. The main prize is the sheer size of China's market for electronics hardware and services.* China is the world's largest market for telecommunications equipment (wired and wireless) as well as a test bed for advanced third-generation wireless communication systems. China is also one of the most demanding markets for computing and digital consumer equipment. Since China produces most of that equipment, it has become the world's third-largest market for semiconductors, which, as we will see below, has generated substantial demand for chip design.

UPGRADING THROUGH TECHNOLOGY DIVERSIFICATION

The 1997 financial crisis and electronics sector downturn in 2000 exposed flaws in the global factory model

Asia's role as the global factory will continue to be an important source for economic growth and the development of industrial capabilities. However, the 1997 financial crisis and the downturn in the global electronics industry in 2000 have brutally exposed the downside of that model. A country is vulnerable if (1) a large share of its exports are electronics, (2) it is highly integrated into GPNs, and (3) it depends to a large degree on exports to the United States for revenue.

In addition, there are decreasing returns to the global factory model.[7] As the capital intensity of such investment increases, it generates less new employment. Local spillovers to domestic suppliers also decline as global contract manufacturers provide integrated manufacturing services, which increases their share of global factory production. Furthermore, much of the global factory investment has remained "footloose," which has led to plant closures and relocation to new lower-cost locales.

Asian firms heavily rely on American, Japanese, and European firms as the dominant sources of new technology. This reflects the heavy concentration of R&D, innovative capabilities, and intellectual property rights (IPR), much of it centered on the United States.[8] For Asian firms, this has resulted in razor-thin profit margins owing to the hefty licensing fees charged by the global brand firms.

Across the region, a broad consensus has emerged that the Asian electronics industry must upgrade to higher value-added and technologically more demanding products, services, and production stages. Such changes require the development of strong innovative capabilities. To achieve this goal, Asian governments and leading electronics and software companies have sought to develop and improve the skills, knowledge, and management techniques needed to create and successfully commercialize new products, services, equipment, processes, and business models.

They have focused pragmatically on what is feasible in view of the fact that the region continues to lag substantially behind advanced nations in the development of a broad-based science and technology system.[9] Instead of jumping right into "technology leadership" strategies to compete head-on with global technology leaders, Asian governments and businesses have

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* In the electronics industry, China has become the main export market for the United States, Japan, Taiwan, and South Korea.

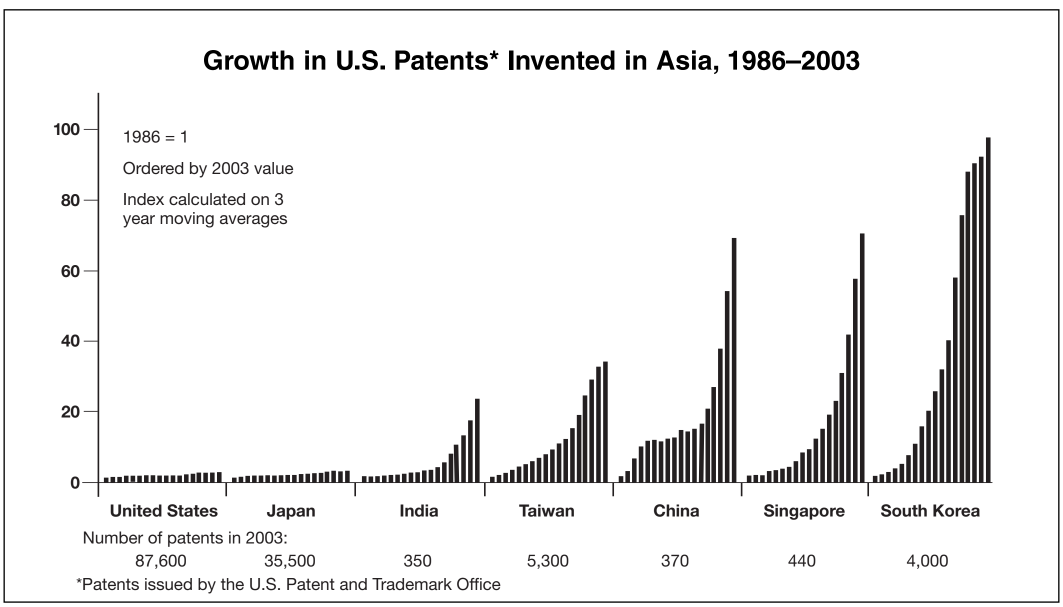
focused on technology diversification. This arguably laid an important foundation for the region's success in attracting innovation offshoring.

Technology diversification, defined as the expansion of a company's or a product's technology base into a broader range of technology areas, focuses on applied research and the development of products that draw on component and process technologies that are not necessarily new to the world or difficult to acquire.[10] Such diversification has enabled Asian firms to build on their existing strengths in manufacturing, process development, and prototype development. They also have been able to leverage their experience in providing knowledge-intensive support services required to raise money and to manage supply chains and customer relations, knowledge exchange, and the development of human resources. Most importantly, technology diversification has enabled Asian firms to use their accumulated capabilities to implement, assimilate, and improve foreign technologies since technology diversification often requires the exchange of knowledge with foreign parties.

ACHIEVEMENTS

The results of these efforts are impressive. Asian governments and leading electronics and software companies have mobilized substantial investments to improve infrastructure (especially for broadband communication), and to support leading-edge R&D programs in a few high-priority areas. South Korea, Singapore, Hong Kong, and Taiwan together with small Nordic countries in Europe lead the world in broadband access and speed. A few regions in China and India that have attracted innovation offshoring are also catching up rapidly.[11]

In addition, gross domestic expenditures on R&D have substantially increased in Asia's five leading electronics exporting countries, with China and Singapore experiencing the fastest rise. This has led to a substantial growth in the output of scientific papers, in citation ratios of these papers, and in the number of patents invented in Asia granted by the U.S. Patent and Trademark Office.[12] As a result, new innovation clusters have emerged for



Source: Hicks, D. "Growth in Asian S&T Capability and R&D Offshoring." Slide presentation at the Council of Foreign Relations, New York, May 24, 2005.

broadband technology and applications in South Korea and Singapore; for mobile communications and digital consumer devices in South Korea, Taiwan, and China; and for software engineering and embedded software development in India.

Some Asian governments and leading companies have made concerted efforts to support research programs and the development of alternative standards. In telecommunications, for example, South Korea's four leading players (Samsung, SK Telecom, KT, and LG) are engaged in serious efforts to become major platform and content developers for complex technology systems, especially in mobile communications. These efforts build on considerable capabilities to develop complex technology systems that have been accumulated in public research labs, like the Electronics and Telecommunications Research Institute (ETRI), and in the Chaebol R&D labs. Examples include TDX (a switching system), and communication systems based on Qualcomm's CDMA (code-division multiple access) standard.

Another important example is China's attempt to develop an alternative third-generation (3G) digital wireless standard, called TD-SCDMA (time-division synchronous code-division multiple access). Datang Telecom, a Chinese state-owned enterprise, and the Research Institute of the Ministry of Information Industry developed the TD-SCDMA standard with technical assistance from Siemens. The International Telecommunications Union (ITU), in turn, approved it in August 2000.*

To accelerate the implementation of this strategy, Datang formed a series of collaborative agreements with global industry leaders to conduct China-based R&D. There is a joint venture with Nokia, Texas Instruments, the South Korean LG group, and Taiwanese ODM (original design manufacturing) suppliers, a joint venture with Philips and Samsung, and a licensing agreement with STMicroelectronics. These agreements provide the Chinese company access to critical design building blocks. Such linkages illustrate the important role that these programs play in attracting innovation offshoring.

SKILLS AND CAPABILITIES

Asia's greatest attraction for innovation off-shoring results from major improvements in its talent pool

Asia's greatest attraction for innovation offshoring results from impressive improvements in the region's talent pool. Building on existing strengths in volume manufacturing, Asian firms have developed a broad range of specialized skills and capabilities. These include quality control and the management of resources, supply chains, and customer relations.

But to remain in the GPNs, Asian firms had to move into product development and, increasingly, into system design and integrated circuit design.[13] Proximity to Asia's vast electronics manufacturing base has been an important asset since product development focuses on manufacturability and the production of commercial samples. As documented in the case study below, Asian firms made substantial progress developing specialized skills required for complex design projects.

Most importantly, according to the National Science Board, Asia's leading electronics exporting countries have substantially expanded "their higher education systems and the high-technology sectors of their economies in an effort to develop internationally competitive

* The two dominant competing global 3G standards are W-CDMA, which is compatible with existing GSM operations and supported by European firms, and CDMA 2000, which is compatible with existing CDMA operations and supported by U.S. firms.

centers of excellence. In the past, these … countries have been the main source of internationally mobile scientific and technical talent, but recently some of them have developed programs designed to retain their highly trained personnel and to even attract people from abroad."[14]

For instance, China now graduates almost four times as many engineers as the United States. South Korea—with one-sixth of the population and one-twentieth of the GDP—graduates nearly the same number of engineers as the United States.[15] China is experiencing explosive growth in Ph.D.-level degrees in science and engineering (S&E), the critical indicator of a country's research capabilities. A recent report prepared for the National Bureau of Economic Research shows that between 1995 and 2003, first-year entrants in science and engineering Ph.D. programs in China increased six-fold, from 8,139 to 48,740. The report concludes that "(a)t this rate China will produce more S&E doctorates than the United States by 2010!"[16]

Such rapid expansion will undoubtedly come at the cost of a declining quality of graduate education, at least outside of a handful of elite universities. A recent McKinsey report shows that, if all negatives are factored in, only 25 percent of India's engineering graduates are suitable for work at global corporations, while the current share in China is only 10 percent.[17]

The supply of engineers in low-wage countries represents as much as three-quarters of the engineering pool in higher-wage countries

However, the report also shows that the current supply of suitable engineers in low-wage countries represents as much as three-quarters of the suitable engineering talent pool in higher-wage countries. This share is substantially higher than the 44 percent share of low-wage countries in the total supply of suitable young professionals in higher-income countries.* Furthermore, the supply of suitable young engineers is expected to grow much faster in low-wage countries than in higher-wage countries. McKinsey projects that by 2008 low-wage countries will supply the same number of suitable young engineers as in higher-wage countries.

Highly skilled knowledge workers are much cheaper in Asia (outside of Japan) than in the United States. For instance, the cost of employing a chip design engineer in Asia is typically between 10 to 20 percent of the cost in Silicon Valley.† Since coordinating cross-continental design teams is likely to add substantial costs, industry experts estimate the net advantage to be between 30 and 50 percent. Cost savings of such magnitude obviously are important for companies that are under constant pressure to improve their return-on-investment. The potential savings also provide an important incentive for innovation offshoring.[18]

ASIA'S GROWING EXPOSURE TO INNOVATION OFFSHORING

Large global corporations are setting a fast pace for innovation offshoring in Asia. For instance, the share of R&D in Asia of U.S. firms has almost quadrupled from 3 percent of $12 billion in 1994 to close to 12 percent of $20 billion in 2002.[19] A recent survey of the world's largest R&D spenders showed that in 2004 China had become the third most important offshore R&D location after the United States and the United Kingdom, followed by India (sixth) and Singapore (ninth).[20] More than half of the responding firms have at least one R&D facility in China, India, or Singapore.

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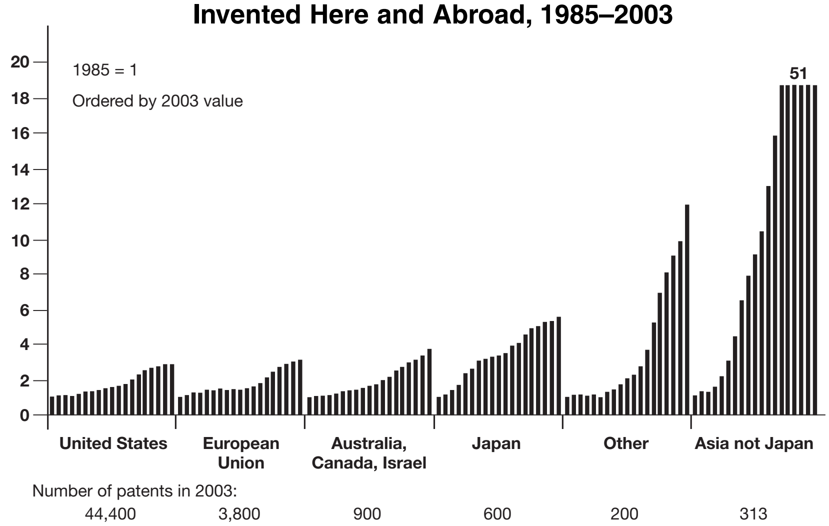
* McKinsey defines "young professionals" as university graduates with up to seven years of work experience. This includes engineers, finance and accounting specialists, generalist professionals, life science researchers, and quantitative analysts. Not included are doctors, nurses, and various support staff.

† This cost comparison includes salary, benefits, equipment, office space, and other infrastructure.

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

The same survey projects that the pace of R&D internationalization will accelerate—as many as 67 percent of the respondents to the United Nations Conference on Trade and Development (UNCTAD) survey stated that the share of foreign R&D will increase; only 2 percent indicated the opposite. Large U.S. corporations are likely to play a critical role in driving this trend. Many have revealed plans to expand their reliance on R&D internationalization. As the following graph illustrates, the number of U.S. company patents invented in Asia has drastically increased over the last few years (albeit from a very low level), outpacing the growth in any other region. Furthermore, Japanese and South Korean firms have indicated they are keen to move beyond their current low levels of R&D internationalization. In short, Asia is expected to receive much of the future R&D internationalization, with China being a more attractive location for future foreign R&D than even the United States or India.

R&D Globalization: Growth in U.S. Company Patents Invented Here and Abroad, 1985–2003



Source: Hicks, D. "Growth in Asian S&T Capability and R&D Offshoring." Slide presentation at the Council of Foreign Relations, New York, May 24, 2005.

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

This has given rise to new and unconventional business models of innovation offshoring that frequently involve foreign-born engineers from Taiwan, China, and India. For instance, there 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 Ph.D. 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 60 engineers at the Beijing facility, 90 percent hold at least a master's degree. Five senior managers based in Santa Clara handle customer relations and provide design building blocks ("silicon intellectual properties," or SIPs) 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 has expanded its services considerably and now provides everything from concept design to the development of SIPs. 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.

The New Mobility of Innovation

Innovation offshoring runs counter to established wisdom. It is widely assumed that for a firm to grow, it must control resources that are valuable, rare, and to a significant extent immobile, and that "a firm's rate of growth is limited by the growth of knowledge within it."[21] A related assumption is 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.[22]

Globalization research reveals that the center of gravity for innovation has shifted beyond the national economy

Only a decade ago, research on the geographical distribution of patents demonstrated that innovative activities of the world's largest firms were among the least internationalized of their functions.[23] Experts assumed that innovation within the firm was and would always be highly localized because it usually requires dense exchange of knowledge (much of it tacit) between the users and producers of the resultant new technologies. Attempts to explain such spatial stickiness of innovation have focused on the *dynamics* of spatial agglomeration within localized innovation clusters.[24]

GLOBALIZATION

There is no question that the demanding requirements of managing complex innovation projects tend to concentrate innovation in the home country. However, research on globalization has clearly established that the center of gravity has shifted beyond the national economy.[25] International linkages proliferate as markets for capital, goods, services, technology, and knowledge workers are integrated across borders.[26] While integration is far from perfect, especially in the latter two markets, it is nevertheless transforming the geography of innovation.[27]

As markets for technology and knowledge workers have globalized, fundamental changes have occurred in corporate innovation management. A gradual opening and networking of corporate innovation systems is giving rise to global innovation networks (GINs) that cut across firm boundaries, sectors, and national borders. Thus, instead of a few preeminent centers of innovation, there are now "multiple locations for innovation, and even lower-order or less developed centers can still be sources of innovation."[28]

Moreover, there is a growing recognition that the balance is shifting from "centripetal" to "centrifugal" forces—i.e., the globalization of markets, technology, competition, and strategy and the resultant opening of corporate innovation systems have boosted the forces for geographical decentralization of R&D. "Pull" factors that attract R&D to particular locations include demand-oriented and supply-oriented forces and policies. "Centrifugal" forces can be stronger than "centripetal" forces when the host country market is large, grows rapidly, and becomes more sophisticated.

Supply-oriented forces are especially important in high-tech industries like electronics.[29] Proximity to global manufacturing bases matters. However, the search for lower-cost overseas R&D personnel and for new ideas and innovative capabilities is increasingly important. As the pace and cost of technological development escalate and as the sources of breakthrough general-purpose technologies proliferate, companies must seek access to a wider range of scientific and technological skills and knowledge than is available in the home market.

How can research teams located at distant locations exchange complex knowledge? The economics of knowledge diffusion, the market for knowledge workers, and the innovators' strategies to protect and exploit intellectual property rights together shape the location of innovation. Equally important, members of a specialized knowledge community—the people who share specialized skills like analog chip design—share rules and codes of exchanging knowledge. Even when dispersed far away in space, members of such communities "will share more jargon and trust among each other than with any outsider within their present local communities. And even when meetings are required, their frequency will not necessarily be as high as to impose co-localization as a necessary requirement for belonging to the epistemic community."[30]

The emergence of multiple innovation clusters underlies the geographic dispersion of innovation

In short, for innovative activities that require complex knowledge 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. The emergence of these kinds of multiple innovation clusters underlies the geographic dispersion of innovation.

Finally, it is important to distinguish between "home-base-exploiting" and "home-base-augmenting" overseas R&D labs.[31] "Home-base-exploiting" overseas R&D has been around for a long time. Its *raison d'etre* 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 during the last decades of the 20th century. Its rationale is "external knowledge sourcing," that is to say, tapping into new knowledge from an increasing number of overseas local innovation clusters, transferring that knowledge back to the home base,[32] and combining these diverse technologies to create new products and processes.[33] Hence, augmenting overseas R&D requires far more than adaptive engineering. It includes product development as well as applied and fundamental research.

DRIVING FORCES[34]

Institutional change through liberalization has played an important role in reducing constraints on the organizational and geographical mobility of innovation. Liberalization includes four main elements: trade, capital flows, foreign direct investment (FDI), and privatization. These different forms of liberalization are related to each other. 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 and more countries to open their capital accounts. More open capital accounts, in turn, encourage liberalization of FDI and privatization tournaments.

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

1. A greater range of choices for market entry, be it via trade, licensing, subcontracting, and franchising (*locational specialization*);
2. Better access to external resources and capabilities that they may need to complement their core competencies (*outsourcing*); and
3. Fewer constraints on the geographic dispersion of the value chain (*spatial mobility*).

Liberalization has catalyzed the expansion of global production and innovation networks

Hence, liberalization has acted as a powerful catalyst for the expansion of global production and innovation networks.

Technology, especially the rapid development and diffusion of information and communication technology (IT), has also increased the mobility of innovation. The high cost and risk of developing IT have 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.[35] 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 audio-visual media.

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. In essence, IT has fostered the development of leaner and more agile production and innovation networks that cut across firm boundaries and national borders.

Liberalization and IT have drastically changed the dynamics of competition and industrial organization. Competition now cuts across national borders. A firm's position in one country is no longer independent from its position in other countries.[36] The firm must be present in all major growth markets (*dispersion*). It also must integrate its activities on a worldwide scale in order to exploit and coordinate linkages between these different locations (*integration*). In addition, competition cuts across sector boundaries and market segments. Mutual raiding of established market segment fiefdoms has become the norm, making it more difficult for firms to identify market niches and to grow with them.[37]

VERTICAL SPECIALIZATION

To cope with the growing complexity of competition, global companies have had to adjust their strategies and organization. No firm, not even a dominant market leader, can generate all the different capabilities internally that are necessary to cope with the requirements of global competition.

Competitive success critically depends on "vertical specialization." Global firms selectively "outsource" certain capabilities from specialized suppliers and they "offshore" them to new, lower-cost locations.

While vertical specialization initially focused on final assembly and lower-end component manufacturing, increasingly it is being pushed into higher-end value-chain stages, including product development and research. To make this happen, global firms have had to adopt collective forms of organization, shifting from the multidivisional (M-form) functional hierarchy to the networked global flagship model.[38]

The electronics industry has become an important breeding ground for this new industrial organization model.* A massive process of vertical specialization has segmented an erstwhile vertically integrated industry into closely interacting horizontal layers.[39] Until the early 1980s, IBM personified "vertical integration." Almost all ingredients necessary to design, produce, and commercialize computers remained internal to the firm. This was true for semiconductors, hardware, operating systems, application software, and sales and distribution.

Many activities that a computer company used to handle itself are now farmed out to layers of specialized suppliers

Since then, however, vertical specialization has become the industry's defining characteristic.[40] Many activities that a computer company used to handle internally are now being farmed out to multiple layers of specialized suppliers. This has given rise to rapid market segmentation and to an ever-finer specialization within each of the above value-chain stages. As firms accumulate experience in managing global distribution and production networks and learn from successes and failures in inter-firm collaboration, they have been able to expand vertical specialization.

These adjustments were especially important in the choice of product and process specialization, investment funding, and human resources management. They feed into each other so that small changes in any of them require adjustments in all the other aspects of the business model.

IBM's transformation during the 1990s from a hardware producer to a supplier of "integrated solutions" services is emblematic of adjustments in product and process specialization. While the share of revenues from hardware declined from 48 percent in 1996

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* The biotech sector of pharmaceuticals, however, has made the most progress pushing vertical specialization into research and development. Ray Hill, a senior R&D manager at Merck, estimates that "99 percent of the world's bio-medical research takes place outside our [big pharmaceutical company] research labs." See "Change of Culture: How Big Pharma is Picking the Best of Biotech as a Sector Starts to Mature," *Financial Times*, January 12, 2006.

to 32 percent in 2003, the share of services rose from 29 percent to 48 percent. IBM's shift out of hardware into services provided a powerful catalyst for similar attempts by other leading global electronics firms.*

The spread of venture capital and related financial regulatory changes drastically altered corporate investment strategies

The spread of venture capital and related regulatory changes in the financial sector drastically changed corporate strategies of investment funding.† U.S. venture capital firms have provided access to a massive infusion of capital from U.S. pension funds as well as hands-on industrial expertise. As a result, start-up companies in the electronics industry have been able to raise capital for high-risk innovation projects. At the same time, global industry leaders increasingly have used stock to attract and retain global talent and to acquire innovative start-up companies.[41]

Both changes in investment funding have led to far-reaching changes in corporate governance. Investment decisions are now primarily oriented toward servicing shareholder requirements. As described below, this has drastically changed the parameters for innovation management. As electronics firms increasingly rely on stock and venture capital, they are under growing pressure to expand productivity and commercialize the resulting intellectual property rights (IPR) as quickly as possible.

In addition, the electronics industry has seen a dramatically diminished commitment to long-term employment. As a result, there has been a substantial increase in the inter-firm and geographical mobility of labor, especially for highly skilled engineers, scientists, and managers. In the United States, the emergence of a "high-velocity labor market" [42] for IT skills is driven by the proliferation of start-up companies, a drastic increase in the recruitment of highly educated foreigners, and the spread of lavish incentives (such as stock options) to induce job-hopping.

These practices have increased the cost of employing IT workers in the United States. For instance, between 1993 and 1999, computer scientists and mathematicians experienced the highest salary growth (37 percent) of all U.S. occupations.[43] Average real annual earnings of full-time employees in California's software industry rose from $80,000 in 1994 to $180,000 in 2000, only to fall drastically to below $100,000 in 2002 after the bursting of the "New Economy" bubble.

But even in the midst of the IT industry recession, employees in the U.S. IT industry continued to earn, on average, far more than workers in most other sectors of the economy, and between five and ten times more than their counterparts in Asia (outside of Japan). In 2002, the average annual wage in the U.S. IT industry was $67,440 ($99,440 in the software industry), compared with $36,250 in all private-sector industries.[44] This has created a powerful catalyst for U.S. IT firms to increase their overseas investment in R&D to tap into the growing pool of educated and experienced IT talent that is available in Asia at much lower wages.

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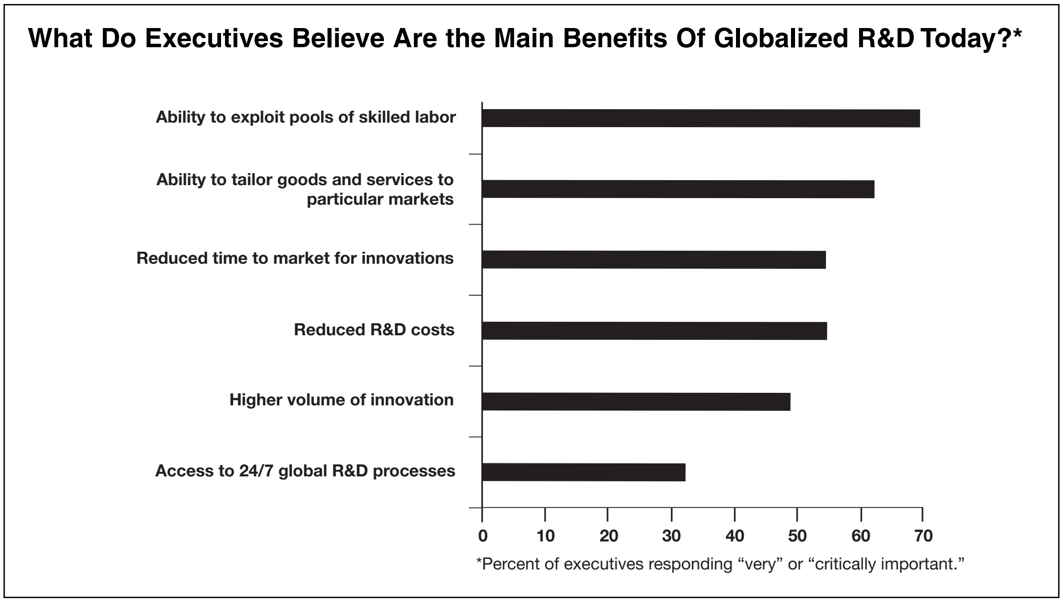
* Dell remained an important exception with its single-minded focus on perfecting low-cost production and supply chain management for commodity-type products. But Dell is now under pressure to adjust its business model.

† Important complementary changes in U.S. financial institutions include the launch of NASDAQ in 1971 (making it much easier for start-up firms to go public), the passage of legislation in 1978 that reduced capital gains tax from 49 percent to 28 percent, and the 1979 decree by the Department of Labor that pension fund money could be invested not only in listed stocks and high-grade bonds but also in more speculative assets, including new ventures.



Source: Economist Intelligence Unit. *Scattering the Seeds of Innovation: The Globalization of Research and Development.* A white paper prepared for Scottish Development International, London, 2004.

CHANGES IN INNOVATION MANAGEMENT

The above transformations in strategy and organization have provoked fundamental changes in innovation management and further enhanced the mobility of innovation. There is a transition under way toward more open corporate innovation systems based on increasing vertical specialization of innovation.

Corporate innovation management must address four tasks simultaneously: (1) to develop innovative capabilities (including R&D);* (2) to recruit and retain educated and experienced knowledge workers; (3) to develop and adjust innovation process management (methodologies, organization, and routines) in order to improve efficiency and time-to-market; and (4) to match all three tasks with the corporation's business model.

The challenge is that no firm, not even a global market leader like IBM, can mobilize all the diverse resources, capabilities, and bodies of knowledge internally. As a consequence, both the sources and the use of knowledge have become increasingly externalized. Firms now must supplement the in-house creation of new knowledge and capabilities with external-knowledge sourcing strategies. There are strong pressures to reduce in-house basic and applied research and to focus primarily on product development and the absorption of external knowledge.[45]

No longer does this externalization of innovation stop at the national border. Firms increasingly need to tap sources of knowledge that are located overseas.[46] The result is that GINs cut across sectors and national borders.[47] According to the most recent *Science and Engineering Indicators* report by 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

* "Innovative capabilities" are defined as the skills, knowledge, and management techniques needed to design, produce, improve, and commercialize "artifacts," i.e., products, services, machinery, and processes.

innovation system increasingly characterized by networking and feedback among R&D performers, technology users, and their suppliers and across industries and national boundaries."[48]

IBM provides a telling example of this transformation from "closed" to more "open" corporate innovation systems. IBM pushed vertical integration to the extreme when it decided in 1964 to bet its future on the development of the 360 family as the global standard for mainframe computers. The computer giant internalized practically all stages of the value chain. It developed the basic components, assembled them into subsystems, designed systems out of these components, manufactured the systems at its own factories, distributed and serviced the systems themselves, and even handled the financing of the systems.[49]

Various forces have shaped IBM's decision to open its innovation system. The recession of the early 1990s brutally exposed the weaknesses of a "closed" system. For the first time since 1946, the company in 1991–93 experienced three years of declining revenues, shrinking profit margins, and deficits totaling $15.9 billion.

In response, IBM pursued a strategy of transforming itself from a hardware producer to a supplier of integrated solutions. The objective of this strategy was to leverage IBM's broad portfolio of intellectual property rights, not only to exclude rival firms, but also to generate new and highly profitable sources of growth. To deliver the best solutions, IBM had to transcend its own R&D by seeking the best technologies and combining diverse technologies into effective integrated solutions. The company's decision to adopt open standards in a variety of areas, including the Linux OS, the Java programming language, HTML, and http protocols facilitated this strategic shift.

IBM realized that it no longer was realistic to try to tightly control use of its component technologies since abundant specialized knowledge had dispersed to other companies and countries. The company substantially reduced the intensity of its R&D. IBM's share of R&D in sales declined from an annual average of 9.84 percent during the 1983 to 1992 period, to an average of 6 percent during the 1994 to 2003 period (IBM annual reports).[50]

IBM shifted the focus of innovation management to technology licensing and became the leader in U.S. patent applications

The company instead shifted the focus of innovation management to technology licensing. Since 1993, IBM has been the leader in U.S. patent applications. In 1990, by comparison, it ranked ninth.[51] Licensing has proved to be more profitable than sales. IBM's licensing revenues grew from $30 million in 1990 to $1 billion in 1998. This amounts to about $750,000 per patent and 10 percent of IBM's net profits. "To generate equivalent profits, it is estimated that IBM would have to sell $20 billion in goods and services."[52] In 2001, IBM received $1.9 billion in royalty payments (amounting to 17 percent of its pre-tax revenues). In comparison, it spent $600 million on basic research during the same year.

IBM's move toward a more open and networked innovation system has culminated in a web of international R&D alliances aimed at accelerating progress in semiconductor technology, developing new applications for its "Power" microprocessor, and generating new markets for its computer equipment and IT services. Industry experts anticipate that IBM's decision to undertake joint R&D and to share capital expenditures with companies that possess complementary capabilities—e.g., Singapore-based Chartered, AMD, Sony, Toshiba, Infineon, and Samsung—will reduce the tremendous costs and risks of developing and producing leading-edge integrated circuits.* Through its "Power.Org" alliance for open business interface standards, IBM has sought to motivate vendors of electronic equipment (especially servers, handsets, and digital consumer electronics) to develop new applications for IBM's "Power" microprocessor architecture.

Interestingly, the "Power.Org" alliance was unveiled in Beijing. The explicit objective was to exploit the huge potential for new applications in the rapidly growing Asian IT markets, particularly in China. According to one well-placed observer, IBM's objective "is not to sell chips but to sell the knowledge and technology needed to help overseas [i.e., Chinese] companies make their own chips and integrate Power into their own products … IBM opens Power to stake its claim overseas and get relief from confining U.S. trade policies."[53]

This implies that IBM's "open innovation system" strategy is seeking to bypass constraints on the development of Asian innovation capabilities caused by restrictive U.S. policies on technology exports of leading-edge microprocessor technology. To the degree that such "open innovation" strategies will strengthen local innovative capabilities, they are likely to facilitate the future expansion of innovation offshoring.

GLOBAL MARKETS FOR TECHNOLOGY

The example of IBM shows that in an open innovation system both the source and the use of knowledge can be external. The firm can create ideas for external and internal use, and it can access ideas from outside and from within. Firms have been able to move to an open innovation system because an increasing division of labor in innovation has given rise to global markets for technology.[54] Global firms can now outsource knowledge needed to complement their internally generated knowledge. Furthermore, they can elect to license their technology and, hence, enhance the rents from innovation.

External knowledge sourcing also can provide a shortcut for late entrants from Asia

There is now much greater scope for external technology sourcing. Global markets for technology imply that a firm's competitive success critically depends on its ability to monitor and quickly seize external sources of knowledge.[55] As demonstrated by Iansiti and West, a company can leverage basic or generic technologies developed elsewhere.[56] This allows it to focus on developing unique applications that better suit the needs of specific overseas markets. Industry leaders can now balance in-house innovation and external knowledge sourcing.

But external knowledge sourcing also can provide a shortcut for late entrants from Asia. For instance, Asian companies that trail behind industry leaders in their in-house technological capabilities can now use external technology sourcing to enhance their in-house innovative capabilities.[57]

Markets for technology also create new opportunities for appropriating innovation rents through technology licensing. The underlying assumption is that once markets for technology exist, one can codify knowledge sufficiently and develop well-defined and protective intellectual property rights.[58] However, an excessive reliance on technology licensing may be risky because it cuts off the company from vital system integration knowledge that it needs for continuous innovation.[59]

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* A company typically needs $3-4.5 billion to establish a factory ("fab") that is capable of producing chips from 12-inch wafers with 90-nanometer process technology. For a leading-edge system-on-chip design, development costs can be as high as $50-80 million.

EVOLVING GLOBAL MARKETS FOR KNOWLEDGE WORKERS

The growing availability of knowledge workers outside the dominant corporations and their increasing geographical mobility have been equally important for the gradual opening of corporate innovation systems. This first happened in the United States after World War II owing to the influence of the G.I. bill. In Europe, Marshall aid for reconstruction and later rounds of EU enlargement expanded the market for knowledge workers. After 1970, the same trend appeared in Japan, and in the newly industrializing economies of East Asia. As demonstrated in Part I, the supply of knowledge workers suitable for work in global corporations now is growing substantially in Asia's leading electronics exporting countries.

Data from the 2000 U.S. census show that in S&E occupations 38% of doctorate holders were foreign born

The result is an evolving global market for knowledge workers, which has created vast new talent sources. At the urging of American business, the U.S. government responded to changes in the knowledge worker market by allowing greater immigration of foreign students and professionals, especially for science and engineering (S&E). Until the turn of the century, the United States was the main beneficiary of the globalization of knowledge workers. The U.S. share of the world's S&E workforce was "disproportionately high" during the second half of the 20th century.[60] It reached its peak during the 1970s when more than 30 percent of the world's tertiary-level students were enrolled in U.S. universities. These institutions granted more than 50 percent of S&E doctorates during that period.

A 1998 NSF study showed that more than 50 percent of the post-doctoral students at MIT and Stanford were not U.S. citizens and that more than 30 percent of computer professionals in Silicon Valley were born outside the United States.[61] Data from the 2000 U.S. Census show that in S&E occupations, approximately 17 percent of bachelor's degree holders, 29 percent of master's degree holders, and 38 percent of doctorate holders were foreign born.

This has enabled U.S. start-up companies to pursue "learning-by-hiring away" strategies. They could rapidly ramp up complex innovation projects with highly experienced personnel that were trained by other corporations or countries. But the main beneficiaries were major global U.S. firms that were able to reduce the cost of research, product development, and engineering by shifting from national to global recruitment strategies.

A recent report prepared by a leading U.S. education economist for the National Bureau of Economic Research argues that a powerful economic rationale is driving the increasing reliance of U.S. firms and universities on foreign-born students and employees—they want to reduce the costs of hiring scientists and engineers. The report states that an increase in the supply of immigrant S&E workers "will, all else the same, reduce earnings and employment opportunities below what they otherwise would have been."[62]

Over the last few years, the United States has faced new challenges in global markets for 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 workforce in the United States and, with the exception of India, in Asia's leading exporting countries. As a result, the growth of global markets for knowledge workers is likely to slow down. This implies that over the next decade or so U.S. electronics firms will find it increasingly difficult to attract—and retain—enough qualified workers, especially scientists and engineers.*

Yet, other causes are self-inflicted. For instance, deteriorating earnings and employment opportunities that result from increased immigration have drastically reduced the incentives for U.S.-born citizens and residents to become scientists and engineers. These privileged social groups have access to alternative careers, such as financial analysts, lawyers, and certain medical professions. The latter provide better earnings and employment opportunities than S&E careers.[63]

Intensifying competition for knowledge workers also reflects negative side effects of the aforementioned changes in corporate strategy. For instance, in their quest to improve return-on-investment (ROI), leading U.S. electronics firms have increased the use of temporary workers and have outsourced so-called non-core activities. The resultant downsizing of permanent work forces has increased the vulnerability of these companies to sudden shifts in demand.

Some global corporations pushed downsizing to the limits, especially after 2000. In the words of one expert, "they're running themselves so lean that if they get a little sand in their gears, the whole organization breaks down."[64] If demand shifts to new product generations that require new technologies, these firms must then search for specialized talent to fill the gaps caused by previous rounds of downsizing. As a result, crisis management has become the dominant concern of human resources managers.

U.S. corporations are responding to the intensifying competition for scarce global talent "by opening high-technology operations in foreign locations, developing strategic international alliances, and consummating cross-national spin-offs and mergers."[65] For many high-tech companies, competing for scarce global talent has become a major strategic concern. As a result, global sourcing for knowledge workers now is as important as global manufacturing and supply chain strategies. The goal is to diversify and optimize a company's human capital portfolio through aggressive recruitment in global labor markets.

Global sourcing for knowledge workers now is as important as global manufacturing and supply chain strategies

Since the turn of the century, most leading U.S. electronics firms have moved R&D and engineering overseas, especially to populous countries like China and India that have emerged as important new sources of lower-cost S&E students and workers.† The demand for "bottleneck skills," such as experienced design engineers for analog integrated circuits, has led to global "auction markets" for knowledge workers. These "auctions" enable knowledge workers to sell their talents to the highest bidder.

Overall, however, the emergence of a global market for knowledge workers seems to have kept a tight cap on increases in remuneration.[66] This is because the leading global electronics firms can tap this market for workers who are readily available for hire and need not require extensive internal training or the inducement of lifelong employment.

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* With the important exception of India, aging populations in China and other leading Asian exporting countries may constrain Asia's future supply of low-cost knowledge workers. In China, one of the by-products of the one-child policy is that in a decade or so many more people will be retiring than entering the workforce. In contrast, India is one of the few countries in which the working-age population is projected to grow for the next 40 years or so, keeping wages low. See Jackson and Howe, *The Graying of the Middle Kingdom.*

† Top U.S. research universities are now moving somewhat belatedly to these new locations in order to tap into the rapidly growing new markets for higher education.

By the same token, this market can be highly volatile and pose substantial risks. At any time, demand for knowledge workers may outstrip supply in some locations and supply will exceed demand in other locations. Especially for more senior and experienced engineers and project managers, demand continues to overshoot supply in Asia's major offshore locations.

In China, for instance, there is a paucity of line managers and project managers well versed in implementing state-of-the-art management approaches. Competition for scarce talent (especially in science and engineering) has intensified, as large Chinese companies, such as Lenovo and Huawei, are now seriously competing for the best talent.* In India, it is less of a problem finding experienced line and project managers owing to India's long-established links with the United States and the roles played by nonresident Indians. But turnover rates are extremely high, and global firms are facing serious problems in establishing effective control and efficient processes.[67]

In well-established offshore locations, global firms conduct 'exciting' R&D projects that attract the best of the local talent pool

The volatility of global markets for knowledge workers reflects a fundamental characteristic of innovation offshoring—its geographic dispersion remains concentrated in a handful of new clusters. This tends to prematurely exhaust the limited supply of suitable engineers, giving rise to severe bouts of localized wage inflation and excessive turnover rates for key personnel. Global corporations are forced to constantly readjust and rebalance their location decisions and network management strategies and to continuously search for and experiment with new locations.

As a result, companies that have accumulated some experience in innovation offshoring are now shifting from "labor-cost arbitrage" to strategies to reduce the extremely high turnover and retain scarce talent. In fact, in well-established offshore locations in Bangalore or Shanghai global firms now are willing to conduct "exciting" R&D projects that can attract the best and brightest of the local talent pool.

At the same time, global firms are constantly seeking to identify new offshore locations with lower-cost populations of knowledge workers, such as lower-tier cities in China and India, or new locations in Vietnam, Romania, Armenia, and Slovakia. But to develop these new locations, global firms must invest in the training of local knowledge workers.†

IMPLICATIONS FOR INNOVATION OFFSHORING

In essence, innovation offshoring reflects the recognition by incumbent market leaders that there is simply no way to prevent knowledge diffusion. Even the most aggressive attempts to slow down such diffusion (such as "black-box" technologies‡) are unlikely to succeed. This

* Until recently, managers working for global corporations could earn 50 percent more than managers working for local Chinese companies. Now, however, leading Chinese companies offer competitive remuneration packages and aggressively headhunt Chinese managers employed at global firms.

† This is somewhat ironic in light of the fact that the same firms are less willing to invest in training in the United States. But it is less puzzling in view of the fact that global firms often seek government support for training. The intensifying incentive tournaments among competing offshore locations suggest that they are quite successful in securing training assistance.

‡ "Black box" technologies are defined as technologies "that cannot be easily imitated by competitors because they are: (1) protected under intellectual property rights, such as patents; (2) made of complex materials, processes, and know-how that cannot be copied; or (3) made using unique production methods, systems, or control technologies" (Ernst, "Searching," 183).

Global firms are expanding their R&D in China so as to tap the vast pool of talent and ideas needed to stay abreast of competitors

explains why global firms now prefer to exploit the diffusion of knowledge, rather than fight rearguard battles to protect against the leakage of knowledge.

There are important additional advantages. For instance, innovation offshoring helps global firms to hedge against failures of internal R&D projects or against slippage in capacity expansion. Innovation offshoring also makes it possible to multiply opportunities for technology diversification. There is a choice between "building-or-buying" new business lines. Furthermore, global firms can accelerate the speed of the innovation cycle and reduce the very high fixed cost of investing in internal R&D.

The transition to open innovation networks has changed the way in which global corporations are using their overseas R&D centers in Asia. A recent study about R&D investment in China by major international companies illustrates this point.[68] The study emphasizes that while cost savings matter, global firms are expanding their R&D in China primarily for strategic reasons. They want to tap into the vast pool of talent and ideas in order to stay abreast of competitors in the increasingly sophisticated markets of China and Asia. The Industrial Research Institute (IRI),* which conducted the study, predicts a substantial increase in innovation offshoring in China. IRI argues that the focus of overseas R&D labs is shifting from support and adaptation to the sourcing of China's emerging technologies and talent pools.

The following taxonomy helps to capture the evolution of R&D labs established by global electronics firms in China. "Satellite" R&D labs, the least developed type of lab, combine elements of "home-base-exploiting" and "home-base-augmenting" R&D. These labs are of relatively low strategic importance, as evidenced by their vulnerability to budget cuts decided by headquarters.

"Contract" R&D labs describe the pure-play version of "innovation offshore outsourcing." For these labs, China's role is confined to the provision of lower-cost skills, capabilities, and infrastructure. While dense information flows link these labs with R&D teams at headquarters and other affiliates, knowledge exchange remains tightly controlled and highly unequal.

The highest stage, "(more) equal partnership" labs, is reserved for those R&D labs of global firms that are charged with a regional or global product mandate. For these labs, barriers to knowledge exchange are supposed to be much lower and may eventually give way to full-fledged mutual knowledge exchange.

Recent research documents that satellite and contract R&D labs continue to dominate.[69] However, there are also examples of (more) equal partnership arrangements, especially related to the development of China's alternative standards in mobile telecommunications, open source software, and digital consumer electronics.[70]

In short, innovation offshoring results from fundamental changes in business organization. "Vertical specialization" is no longer restricted to the production of goods and services. It now extends to all stages of the value chain, including research and new product development. Over the years, this process has taken on an increasingly international dimension, the result being that corporate innovation management can "integrate distinctive knowledge from around the world as effectively as global supply chains integrate far-flung sources of raw materials, labor, components, and services."[71]

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* Members of the Industrial Research Institute (IRI) include more than 240 leading global manufacturing firms that perform more than two-thirds of the industrial R&D in the United States.

In other words, global firms construct global innovation networks to improve the productivity of R&D by accessing knowledge from cheaper, non-traditional locations. As the number of specialized suppliers of innovation modules increases, this provides a powerful boost to the organizational and geographical mobility of innovation. Global firms are now seeking to integrate geographically dispersed innovation clusters into global networks of production, engineering, development, and research.

Since the turn of the century, these networks have been extended to emerging new innovation clusters, especially in Asia. This trend is expected to provide global firms with a powerful new source of competitive advantage because they can now quickly generate more and higher-value innovation at lower cost.

Case Study on Chip Design[72]

The recent expansion of chip design in (non-Japan) Asia provides an interesting test case for the study of innovation offshoring. From practically nothing during the mid-1990s, Asia's share of chip design shot up to around 30 percent in 2002.* Taiwan has emerged as an important new location, with South Korea following closely behind. Chip design is growing rapidly in China and India, as well as in Singapore and Malaysia.

CHIP DESIGN MOVES TO ASIA

Chip design activities are typically divided into routine functions ("design implementation") and stages of design that center on conceptualization ("system specification"). Providers of design services and, more recently, providers of electronic manufacturing services focus primarily on implementing designs. This reflects long experience in board-level design that goes back to the early 1980s,[73] but today covers very complex multilayer boards.

Asian firms possess a broad portfolio of design implementation capabilities owing to the experience they have accumulated in board-level design and fabrication of integrated circuits. For Taiwanese design houses, in particular, design implementation remains an important strategic focus. They compete on the speed, cost, flexibility, and quality of such services.

But there are also strong incentives for Asian firms to develop "system specification" capabilities. Such capabilities are necessary to reap innovation rents via premium pricing. In addition, "system specification" is a key element of strategies to develop global brands.

As mentioned, Taiwanese design houses have sought to distinguish themselves as suppliers of design building blocks, the so-called SIPs. However, global industry leaders like Intel and Texas Instruments are the main drivers behind the development of "system specification" capabilities in Asia. They are conducting cutting-edge integrated chip development projects in some of their Asian R&D centers. In addition, Asia's leading system companies, especially

* Of course, this is still far smaller than North America's share of 60 percent. However, Asia is the fastest growing market for electronic design automation (EDA) tools, growing 36 percent in the first quarter of 2004, compared with 5 percent growth in North America, 4 percent in Europe, and 2 percent in Japan. (See EDA Consortium, *Market Statistics Service Survey*, August 2004 and iSuppli, *China's Fabless Firms Race Beyond Foundation Stage.*)

from China and South Korea, are producing innovations in the design of complex system architectures,* primarily for wireless telecommunication systems.

Design complexity has also improved in terms of (1) the line-width of process technology, measured in nanometers; (2) the use of analog and mixed-signal design, which are substantially more complex than digital design; (3) the share and type of system-level design, such as system-on-chip, system-in package, structured ASICs; and (4) the number of gates used in these designs. The primary carriers of complex design projects are offshore R&D centers established by global semiconductor firms, foundry service providers, and design houses.

A few leading Asian firms from China, India, South Korea, and Taiwan are conducting design projects at the technology frontier. By nationality, South Korean and Taiwanese firms generate the most complex designs. Chinese telecommunications equipment vendors also produce complex designs. The rest of the Asian sample firms are at least one generation behind the cutting edge in design complexity. They are positioning themselves as fast, but cheaper followers.

DRIVERS OF CHIP DESIGN OFFSHORING

What forces are driving the offshoring of chip design to Asia? As mentioned earlier, supply-oriented forces attract global firms. The cost of employing a chip design engineer in Asia is typically between 10 and 20 percent of the cost of employing a design engineer in Silicon Valley.†

Demand factors are equally important, however. Global firms emphasize the importance of having design capabilities close to the rapidly growing and increasingly sophisticated Asian markets for communications, computing, and digital consumer equipment. They also want to be able to interact with Asia's leading users of novel or enhanced products or services. If China succeeds in setting alternative standards for 3G mobile communications, for example, global firms will have to locate chip design in Beijing to address the specific requirements of such standards.

To penetrate Asia's markets, U.S. high-tech companies have tried to expand their 'platform leadership' strategies there

To penetrate Asia's growth markets, semiconductor giants like Intel and system companies like IBM have tried to expand their "platform leadership" strategies across the region.‡ For mobile communication systems, IBM and other major system companies are expanding their Asian chip design centers to establish their own "platform" designs as *de facto* standards in the region.

Global firms emphasize that Asian policies, such as the provision of low-cost but high-quality infrastructure and other incentives, can play an important role in attracting chip

* "Architecture" refers to "the partitioning of the … [computer] system into components of a given scope and related to each other functionally and physically through given interfaces. From a given architecture flows the design of components' functions and how they relate to each other." Gawer and Cusumano, *Platform Leadership*, 18.

† These costs comparisons include salary, benefits, equipment, office space, and other infrastructure.

‡ The overriding purpose of "platform leadership" strategies is to leverage the existing market power of industry leaders into the control of "systemic architectural innovations" (Gawer and Cusumano, *Platform Leadership*, 39). For example, Intel has attempted to extend its control over microprocessors by creating widely accepted architectural designs that increase the processing requirements of electronic systems and, hence, the market for Intel's microprocessors.

design to particular locations.[74] On the negative side, global firms are concerned about obscure and unpredictably changing regulations and weak IPR protection in Asia.

Asian governments played a powerful catalytic role for indigenous industry by establishing critical infrastructure, support industries, and design capabilities that enabled firms to invest in and upgrade chip design.[75] Some Asian firms maintain that diverse government policies and regulations have shaped peculiar features of product and factor markets. For example, differences in Asian financial markets have created diverse approaches to investment finance that have influenced the volume and direction of chip design investment. Taiwanese firms that rely primarily on equity have reported that they feel pressured to produce high margins so they can upgrade their design capabilities.*

Finally, Asian firms emphasize that progress in chip design owes much to concerted efforts by both governments and leading Asian companies to establish new sources of innovation and global standards. In the telecommunications sector, China's attempt to develop an alternative third generation (3G) digital wireless standard (TD-SCDMA) also has created a powerful motivation for global and Asian firms to expand their chip design activities in that country.

INNOVATION MANAGEMENT

SoC design has enabled firms to disintegrate the design value chain as well as to disperse it geographically

But how can global firms design chips at multiple locations, particularly given the extraordinary complexity of the design process? And how can design teams exchange complex design knowledge across borders and from distant locations with different levels of economic development? The answers to these questions may be found by examining changes in innovation management that affect the methodology and organization of chip design.

Until the mid-1980s, global system companies and semiconductor firms did almost all their chip design in-house. Vertical integration focused on the design of an individual component to be inserted on a printed circuit board. Since the mid-1990s, however, there has been an upheaval in chip design methodology† owing to intensifying pressures to improve design productivity combined with increasingly demanding performance features of electronic systems.

"System-on-chip" (SoC) design combines "modular design"‡ and design automation to move design from the individual component on a printed circuit board closer to "system-level integration" on a chip.[76] SoC design has fostered vertical specialization in project execution, enabling firms to disintegrate the design value chain as well as to disperse it geographically. This gave rise to complex, multilayered global design networks (GDNs) with variable configurations. For instance, an embedded microcontroller for a mobile handset requires a different GDN configuration than the design of a graphic chip.

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* Taiwanese firms develop "slightly more complex designs on average at slightly higher design productivity rates" than Chinese firms. (V. Nanda, "IC Design House Survey 2003," www.eettaiwan.com/, accessed February 5, 2006.) However, even these relatively small differences in design complexity and productivity can provide very substantial rewards. Taiwanese design houses were paid roughly three times as much as their Chinese counterparts.

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

‡ "Modular design" is a particular design methodology in which parameters and tasks are interdependent within units (modules) and independent across them.

Three GDN layers can be distinguished:

1. The network core encompasses five strategic groups of firms. A "system company" (like IBM) defines the concept, but may well outsource everything else. SoC design may take place within the "system company," an integrated global semiconductor firm (like Intel), or a fabless design house (like Xilinx), or a combination of these. Chip fabrication and assembly also may be outsourced to specialized suppliers.
2. A secondary GDN layer consists of suppliers of tools for electronic design automation (EDA), verification, and chip testing. This layer also includes SIP licensors and design implementation services.
3. A third layer may involve system contract manufacturers, such as Flextronics or Taiwan's Foxconn.

Initially, vertical specialization loosened the bonds between design and fabrication. This process started with ASIC (application-specific integrated circuit) design, where the goal was to avoid the high cost and time required to design a full-custom chip.* The Taiwan Semiconductor Manufacturing Company (TSMC), established in 1987, was an important catalyst. TSMC provides contract chip fabrication ("silicon foundry") services for "fabless" design houses that outsource chip fabrication and target specialized niche markets. Until the early 1990s, GDNs were centered on the well-known symbiotic fabless/foundry relationship, and hence retained a relatively simple structure.

Over time, however, vertical specialization has increased the number and variety of network participants, business models, and design interfaces, bringing together design teams from companies that drastically differ in size, market power, location, and nationality. A SoC design network described in one interview included the following participants:

- A Chinese system company defined the system architecture;
- A Taiwanese contract manufacturer produced the resulting electronic equipment;
- An American integrated global semiconductor firm provided a design platform;
- A European firm provided an embedded processor as an important design building-block.

Additional network participants included:

- Fabless design houses from the United States and Taiwan;
- Silicon foundries from Taiwan, Singapore, and China;
- Chip-packaging companies from Taiwan and China;
- Tool vendors for design automation and testing from the United States and India; and
- Design support service providers from various Asian countries.

Research indicates that geographic proximity can become a disadvantage when a particular chip design project requires a large number of contributors with diverse knowledge sets and capabilities. It can become increasingly costly to bring together a large group of very diverse

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

people at one location. When concentrated there, especially in the home country, such design groups may become too powerful and constrain productivity growth. This potential dynamic provides yet another strong rationale for global firms to offshore chip design to Asia.

SKILL REQUIREMENTS AND WORK ORGANIZATION

Many Asian governments are pursuing policies to increase the supply of well-educated, experienced design engineers

Skill requirements and work organization are of increasing importance as push factors for design offshoring. Global firms emphasize that both the United States and Europe have failed to train enough design engineers for the next technology generation, giving rise to a serious "skill bottleneck." More and more governments in Asia are pursuing policies to increase the supply of well-educated and experienced design engineers. As a result, design engineers in some Asian countries—especially Taiwan, South Korea, Singapore, Malaysia, China, and India—are trained using the latest tools and methodologies. This has been possible because of the emergence of a global market for service providers of education and training for specialized bottleneck skills in engineering and management.

Asia's leading electronics exporting countries have been quick to develop their own private and public design training institutions to accelerate the development of new specialized chip and system design clusters. These training efforts are especially dynamic in India and Northeast Asia. And these efforts have proved successful, attracting support from leading EDA tool vendors. Once Asian designers have gained practical experience, this may give them an advantage over designers in the traditional centers of design excellence in the United States.

Equally important, global chip design firms are under tremendous pressure to increase design productivity and to accelerate time-to-market.[77] Hence, they are seeking to increase workloads and cap the 1990s-era remuneration of design engineers. SoC designers now work "six days per week, twelve hours per day, with intense pressures to meet the time-to-market requirements for design."[78] But as pressure grows in the United States to expense stock options, it is difficult to see why designers would be willing to keep up with such health-destroying workloads.

In Taiwan and China, however, that may be different. The income taxation systems in those two countries enable individuals employed by semiconductor firms to receive company stock and options but not be taxed to any significant degree if they choose to sell the stock. As a result, Taiwanese and Chinese firms arguably "have a competitive advantage … with respect to competition for talent that other firms cannot match."*

KNOWLEDGE SHARING

Offshoring design projects to Asia's new specialized electronics industry clusters poses very demanding requirements for knowledge sharing. Not only are the Asian locations far away geographically from Silicon Valley, but their stages of development and economic institutions also differ substantially from the home country locations of global firms. There are vast differences in labor markets, education systems, corporate governance, and legal and

* In Taiwan and China, employees of semiconductor firms who have received stock as compensation are taxed on the face value of the shares, not the market value. The latter is often many times higher than the face value, given the rapid growth of semiconductor firms in both countries. See Howell et al., *China's Emerging Semiconductor Industry.*

regulatory systems. These differences complicate transactions and the knowledge exchange required to support these transactions.

Thus, it will take time to develop robust and efficient forms of offshore chip design. Transnational knowledge communities,[79] such as professional peer group networks, and Asia's large diaspora of skilled migrants and "IT mercenaries" will serve as important "enabling" factors. Research shows that these networks help to facilitate the exchange of complex design knowledge. Equally important, informal social networks can provide much needed experience and links with markets and financial institutions. They also can help to reverse the brain drain and bring back to Asia experienced project managers and engineers.

Conclusions and Policy Suggestions

Innovation offshoring poses a fundamental challenge to U.S. technology leadership, economic growth, and prosperity. However, the United States still lacks a realistic long-term strategy to respond to Asia's rise as an important location for innovation offshoring. Policy suggestions vacillate between fear—"hollowing-out of U.S technology leadership"—and complacency—"U.S. technology leadership will always remain unchallenged."

The simple metaphor—Asia's rise versus America's decline—is clearly misleading. There is no threat to U.S. technology leadership, at least for now. No serious observer would claim that China, South Korea, India, Taiwan, Singapore, and Malaysia could soon overtake the dominant centers of innovation in the United States, Europe, and Japan. Indeed, there is ample evidence of a persistent U.S.-centric concentration of the sources of innovation:

- Since the late 20th century, American firms have raced ahead in the most prized areas of technological innovation, as far as these can be measured by patent statistics. The U.S. "innovation score" has more than doubled from 41 (in 1985) to almost 101 (in 2002), a rate far better than for any other country.* In 2002, all 15 leading companies with the best record on patent citations were based in the United States, with nine of them in the electronics industry.
- The 700 largest R&D spenders, most of them large U.S. firms, dominate global R&D spending. They are responsible for close to half of the world's total R&D expenditures and more than two-thirds of the world's business R&D.[80]
- More than 80 percent of the 700 largest R&D spenders come from only five countries — first and foremost, the United States, followed by Japan, Germany, the United Kingdom, and France.

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* The U.S. "innovation score" measures the number of patents granted by the U.S. Patent and Trademark Office (PTO), multiplied by the so-called "citation index" that indicates the value of these patents. The citation index measures the frequency of citation of a particular patent. When the PTO publishes patents, each one includes a list of other patents from which it is derived. The more often a patent is cited, the more likely it is a pioneering patent, connected with important inventions and discoveries. An index of more than one indicates that patents are cited more often than would be expected for a specific group of technologies, while less than one indicates they are cited less often than expected. F. Narin, *Tech-Line Background Paper* and CHI/MIT, *Report on "Innovation Scores" Survey, 2003* (www.CHI.com/ and www.chiresearch.com/, accessed January 23, 2005; company acquired, site discontinued).

Fundamental New Challenges Require New National Strategy

Nevertheless, there are reasons to expect a longer-term erosion of the U.S. leadership position. There is a real danger that Asia's rise as an important location for innovation offshoring may challenge U.S. competitiveness in international trade and investment. It is thus time to accept that the United States no longer is preordained to lead the world in innovation.

It is also time to reconsider the tacit assumption that underlies much of U.S. policy-making—that the IT industry will move offshore, including product development and research, and that "the future is in biotech."* Instead, U.S. policymakers should begin a dialogue to develop a new, integrated national strategy on innovation. Such a strategy requires input from all actors involved in innovation. These would include the producers of new ideas (the knowledge workers), the corporations that provide high-risk financing to translate ideas into innovations, the users of innovations, and governments. Ideally, the dialogue would help to identify realistic policy responses to the following fundamental new challenges:

1. ***Talent pool:*** What policies and strategies can help the United States to compensate for the loss of R&D employment and real income—especially in the electronics industry—that results from innovation offshoring?

2. ***Markets:*** Can accelerating market growth in the new offshore locations in Asia compensate U.S. firms for the slowdown in market growth that they are now facing in important markets in the OECD core region?

3. ***Innovative Capabilities:*** How can the United States avoid a hollowing-out of the nation's production and innovation system? What policies can help to contain the leakage of essential intellectual property?

4. ***National Research Priorities:*** In light of the vast untapped opportunities for break-through innovations in information and communications technologies, what policies can help to reestablish support for university research in areas like computer science and electronic engineering?

5. ***New Competitors:*** What policies will enable U.S. firms to cope with much more broad-based competition from Asian companies that covers all stages of the innovation value chain?

6. ***Future Scenarios:*** Which of the following scenarios is likely to determine the future U.S.-Asia division of labor in innovation?

    - **Hierarchical:** The United States can sustain selective and tightly controlled off-shoring of lower-end innovation tasks and capabilities;

    - **Complementary:** U.S.-led global innovation networks combine system integration capabilities in the United States with lower-cost offshore development of intellectual property; or

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* That assumption needs to be qualified in light of the substantial progress in biotechnology in countries as diverse as China, India, Singapore, South Korea, Cuba, and Iran.

- **Unequal interdependence:** There will be coexistence of architectural innovations and new standards developed both in the United States and in Asia, but the United States will continue to shape the terms of interdependence.

The following *generic* policy suggestions highlight a few critical challenges for policymakers. These suggestions are highly selective. Their main objective is to initiate an open debate about how to reduce the economic and social costs of the massive adjustments that innovation offshoring is likely to impose on the U.S. economy.

1. IMPROVE DATA COLLECTION AND ACCESS

It is impossible to begin a national policy dialogue on innovation offshoring without improving substantially collection of and access to data. However, there currently is an extreme poverty of useful data. In fact, a recent report by the Committee on National Statistics, prepared for the National Research Council, argues that, except for statistics on formal R&D spending, patents, and some aspects of science and engineering education, innovation-related data are extremely limited.[81]

Data collection pertaining to global markets for knowledge workers should be entrusted to an international organization

Most importantly, there is a glaring lack of statistics about how many R&D jobs have been offshored from the United States to Asia and in what industries. According to a recent report prepared for the National Bureau of Economic Research, "the U.S. government does not measure the number of jobs offshored."[82] This makes it difficult to develop sound government policies to deal with the negative impacts of innovation offshoring.

It is time to develop robust and widely accessible databases on evolving global markets for knowledge workers and the migration of science and engineering jobs. As innovation offshoring cuts across multiple national borders, the collection of such data should be entrusted to an international organization.

One possibility would be to charge the OECD Secretariat with the creation and maintenance of global databases. Based on the data collected, the OECD might then propose policies governing the trade of skilled labor among countries. These efforts could build upon established institutional arrangements for negotiating and regulating international trade, finance, and intellectual property, such as the World Trade Organization (WTO), the Bank of International Settlements (BIS), the International Monetary Fund (IMF), and the World Intellectual Property Organization (WIPO).

Policies should also reduce the negative side effects of otherwise well-meant regulatory restrictions on information disclosure. An important example is the "Fair Disclosure" regulation (Regulation FD). This regulation stipulates that corporations must release market-sensitive information to all investors at the same time. It also foresees heavy fines if information leaks out to other people.*

While the intention of the U.S. Securities and Exchange Commission was to improve access to information on public companies for individual investors, the opposite has happened. Companies have restricted communications because of a fear of violating Regulation FD. They also have used this regulation as a cover if they do not wish to share certain information

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* Individual company policies on the "fair disclosure" regulation (*Regulation FD*) are described on the investor relations webpages found on the websites of most leading U.S. electronics firms.

with analysts.[83] In short, the regulation has had a significant negative effect on the data that one is able to collect. This seriously constrains research that is necessary to inform policymaking.

2. ADDRESS 'HOME-MADE' CAUSES OF INNOVATION OFFSHORING

Many experts agree that U.S. policy responses to innovation offshoring should seek to sustain and build on existing strengths of the U.S. innovation system. Specifically, Silicon Valley and Route 128 are still among the best places to be for high-risk, knowledge-intensive innovation activities. This is because such locations typically include a broad portfolio of support services —including legal, finance, and property development—that facilitate rapid adjustments of business models to changing requirements of markets and technology. These are also privileged places to collect strategic market intelligence from the most demanding lead users.

Additional strengths of the U.S. innovation system include (1) the presence of the world's leading research universities, (2) an unrivaled exposure to leading-edge management practices for R&D projects, and (3) a high mobility of knowledge workers that facilitates quick and relatively hassle-free knowledge diffusion.

However, there is also a growing recognition that important weaknesses of the U.S. innovation system have acted as "home-made causes" of innovation offshoring. Two types of policy responses—support policies for corporate innovation and policies to upgrade the U.S. pool of knowledge workers—may help to ensure that the United States retains the best environment for innovation.

3. SUPPORT POLICIES FOR CORPORATE INNOVATION

According to William Brody, president of Johns Hopkins University and co-chairman of the U.S. Council on Competitiveness's National Innovation Initiative, the United States is facing a serious challenge: "We are losing our collective will to fund basic research … [which] has failed to demonstrate a return on investment that satisfies the ravenous appetite of financial markets for short-term earnings growth."[84]

The U.S. needs policies that facilitate the supply of risk-tolerant but patient corporate innovation finance

There is an obvious need for policies that facilitate the supply of risk-tolerant but patient corporate innovation finance, whether through the venture capital business model or through corporate venture capital. Policies to mobilize patient risk capital for innovation have focused on the provision of tax incentives and on the protection of intellectual property rights. These are legitimate concerns, but it is necessary to adjust such policies to the new requirements posed by innovation offshoring.

Tax policies: Tax policies should link incentives to performance requirements and to early-stage investments in innovative start-up companies. Good examples are the following recommendations of the Council on Competitiveness:

- "The federal government should provide a 25 percent tax credit for early stage investments when made through qualified angel funds. The individuals participating in these funds would need to make a minimum investment of $50,000 each year in order to receive the tax credit. Acceptable investments would be restricted to those that meet requirements for revenue size and age of firm."

- "Enact a permanent, restructured research and experimentation tax credit (the so-called R&D tax credit) and extend the credit to research conducted in university-industry consortia."[85]

The U.S. also needs policies to help counter new entry and exit barriers for innovative start-up companies

The United States also needs new policies that would help to counter new entry and exit barriers for innovative start-up companies. One of the traditional attractions of the United States, particularly Silicon Valley, was the start-up market. If talented engineers were laid off or wanted to leave their company, they would have good opportunities to launch innovative design companies that focus on market niches with high growth potential.

These opportunities have shrunk substantially as a result of the brutal losses caused by the bursting of the "Internet bubble." Other factors, such as a substantial increase in the minimum funding requirements, also have served to create a more hostile environment for innovative start-up companies.

Intellectual property rights (IPR): Debates about IPR have focused on how to adjust U.S. intellectual property rights policies to maximize incentives for the generation and broad diffusion of innovations. The National Research Council studies on the reform of the U.S. patent system recommended the following:

- Institute a post-grant open-review procedure for U.S. patents;
- Discontinue the practice of diverting patent application fees to general revenue and provide the U.S. Patent and Trademark Office with sufficient resources to modernize and improve performance; and
- Leverage the patent database as an innovation tool.[86]

These measures are not enough. There are significant imperfections in the U.S. patent system.[87] It is often costly to reap the benefits of IPRs, and small firms may face greater difficulties than large corporations in patenting their inventions.

Even more important is the so-called "anti-commons" problem.[88] It is unrealistic to assume that each patent is associated with one innovation only. In complex technology systems, innovation is systemic and cumulative, requiring many different pieces of knowledge, some of which may be patented and owned by companies with conflicting interests. Typically however, IPR protection is fragmented. The resulting constraints to innovation can be substantial. For the inventor, the cost of "inventing around" blocking patents can be extremely high. And the higher these costs, the weaker the innovator's bargaining power in licensing negotiations.

This raises two important but very tricky policy questions. How should different contributors be rewarded? And who is likely to capture the most benefits? While institutional arrangements for IPR protection matter, the outcome is primarily determined by bargaining power. This suggests how difficult it would be to reform the U.S. IPR regime in a meaningful way.

4. UPGRADE THE U.S. TALENT POOL OF KNOWLEDGE WORKERS

The United States must upgrade its talent pool of knowledge workers if it is to counter possible negative impacts of innovation offshoring. Such policies should address the following challenges:

- Provide incentives to increase the number of S&E graduates in the United States;
- Complement formal education in S&E with “soft” capabilities such as entrepreneurship, knowledge integration, and multidisciplinary and cross-cultural management; and
- Encourage skilled foreigners to continue immigrating and reduce possible negative impacts on U.S. knowledge workers.

Provide incentives to study science and engineering: Increasing the number of S&E graduates in the United States requires a multipronged approach.[89] There is bipartisan support in Congress for a substantial increase in federal funding for basic research and for scholarships in math, engineering, and science. President Bush outlined such plans in the 2006 State of the Union address under the rubric of “The American Competitiveness Initiative.” If funded, the initiative would double R&D funding for universities at a cost of $50 billion over the next 10 years and roughly $900 million in 2007. At this stage, however, it is unclear whether Congress will appropriate sufficient resources to implement the plan effectively.[90]

Private business must join the government in bearing the burden of improving the American educational system

It is important for private business to join the government in bearing part of the burden of this investment. Without a broad participation, it would be difficult to cope with the substantial challenges of improving the American educational system. As Segal and Yochelson rightly emphasize, “top-down federal spending alone will not win the race for global leadership in science and technology. It will take a hands-on commitment from all involved in the U.S. innovation enterprise to build world-class talent from the bottom-up … [F]ederal dollars alone are unlikely to shape the career choices of American students. Scholarships may be a factor for some, but they cannot trump market forces.”[91]

A senior product development engineer in Minneapolis, Minnesota, shares this view. He notes that “(a)s long as graduates from the top MBA and law programs receive starting salaries that are almost twice those received by graduates who earn advanced degrees at the top science and engineering institutions … the former will most likely outnumber the latter.”[92]

An additional disincentive to the study of science and engineering is the increasing uncertainty about job prospects. Research reveals widespread anger and frustration among Silicon Valley electronic engineers about offshoring of engineering jobs to Asia. Some of them emphasize that they can no longer recommend to their children to study engineering. The increase in the numbers of financial analysts, lawyers, and certain medical professions (reported, for instance, in the National Science Board’s *Science and Engineering Indicators 2004*) indicates that many students, in fact, have heeded this advice. This has caused a serious domestic brain drain in the U.S. S&E community.[93]

Incentives to study science and engineering should by no means be limited to U.S. citizens. There are compelling arguments for encouraging talented foreign students to come to the United States for advanced graduate studies and to stay here after graduation to work in private business or to join the faculties of American universities. One of the distinguishing features of the United States has been its openness to foreign students and scholars. These two communities have made important contributions to U.S. research and innovation.

The latest “Science Engineering Indicators” report of the U.S. National Science Board documents a dramatic decline in the number of visas issued to foreign students, foreign high-tech workers, and foreign scholars following the September 11, 2001, terrorist attack.

It identifies two causes: (1) a decrease in the number of visa applications and (2) a substantial increase in the proportion of visa applications rejected by the U.S. Department of State.[94]

The recent rising trend line in foreign student enrollments suggests that the U.S. government has corrected some of the visa application procedures that caused the downturn. But far more must be done to reestablish this country as a primary location for foreign students and scholars. This is all the more necessary in view of the increased global competition for graduate students, which, in the longer term, may prevent the United States from entirely recovering the market share it has enjoyed in graduate education.

Develop complementary soft capabilities: Our research shows that formal education in science and engineering *per se* is no longer sufficient to make engineers employable in corporate R&D. As convincingly demonstrated by Donald A. Norman in his analysis of the technology-centered bias of the computer industry, "The technology is the easy part to change. The difficult aspects are social, organizational, and cultural."[95]

The growing importance of complementary soft capabilities is due to the dramatic changes described in the previous section about corporate R&D organization and the resultant spread of GINs. More than ever before, it is now necessary to complement formal education in specialized fields of engineering with a broad range of soft capabilities. These might include a capacity to sense and respond to market trends before others take note (entrepreneurship), a capacity to work in and to manage multidisciplinary and cross-cultural projects, and a capacity to complement analysis with interpretation.

Lester and Piore emphasize that U.S. higher education in science and engineering tends to combine an excessive specialization with too much focus on analysis, while neglecting interpretation and knowledge integration. In their view, innovation requires both analysis and interpretation. But analysis is much easier to teach and understand than interpretation. The purpose of analysis is to solve problems. One divides the problem into a series of discrete and separable components and assigns each one to a knowledgeable specialist. Analysis works best when alternative outcomes are well understood and can be clearly defined and distinguished from one another.

But innovation hardly ever fits this pattern. Uncertainty and unpredictability are its defining characteristics. Analysis therefore needs to be complemented by interpretation, such as "a new insight about a customer, a new idea for a product, [or] a new approach to producing or delivering it."[96] For this to happen, S&E students need exposure early in their studies to "real world" innovation projects in diverse companies through internships and other arrangements.

S&E students need exposure early in their studies to 'real world' innovation projects in diverse companies

Equally important is an exposure to other countries. American students "need international knowledge and inter-cultural communications skills that young graduates around the world already receive as part of their higher education."[97] In contrast to Asian students, a large majority of American students will never study or work as interns abroad during their student careers. According to Jim Hogan, a veteran Silicon Valley venture capitalist, "we live in an insular society. By sending students to Asia, for instance, they begin to understand global competition."[98]

In short, S&E students need training in business, an understanding of international law and business, and an understanding of how to manage, or at least how to work effectively within global production and innovation networks. This requires a multidisciplinary approach to education instead of majors that are narrowly defined by (frequently outdated) measures. It also requires strong knowledge-integrating capabilities, not just analysis.

Encourage skilled foreigners to continue immigrating: One of the most contentious issues is the immigration of skilled foreign knowledge workers. Industry associations and the big research universities support a substantial increase in the number of entry permits for highly skilled professionals. The American Electronics Association (AEA), for example, argues that the United States "needs to decrease the bureaucratic and regulatory barriers delaying, preventing, and discharging high-skilled workers from entering the U.S. workforce … . Immigration is a critical component for maintaining a strong and vibrant technological workforce."[99]

Industry observers argue that initiatives aimed at restricting entry of foreign students and limiting issuance of work permits for foreign engineers do not address the main competitive challenge: "American students are confronted with competition not only from qualified foreign students in the United States, but from … [chip] designers demanding lower salaries in their home country."[100]

The U.S. needs skilled immigrants such as engineers and scientists since these fields are not attracting many Americans

Hence, policies to restrict entry to the United States through visa restrictions provide a powerful incentive for U.S. high-tech firms to accelerate innovation offshoring. In fact, the AEA concludes: "If companies cannot find enough qualified workers domestically and the barriers to employing foreign workers remain high, companies will go to where the workers are located."[101]

This plea for expanding high-skilled immigration is supported by economists who argue that the migration of workers, like free trade in goods, is not a zero-sum game, but one that usually benefits the sending and the receiving country. Experts also point out that the United States needs skilled immigrants such as engineers and scientists, especially in high-tech industries such as IT and biotechnology, since these are fields not attracting many Americans.[102]

But there is also considerable fear that the visas are being used to bring in cheap foreign workers who replace Americans. Hira and Hira argue that the current H-1B and L-1 visa system is "tantamount to dumping, defined by the U.S. International Trade Commission as 'the sale or likely sale of goods at less than fair value.' In this case, the companies are bringing in labor from abroad at less than fair value."[103]

This gives rise to a fundamental dilemma captured effectively by Gary S. Becker, the 1992 Nobel Laureate in Economics: "To be sure, the annual admission of a million or more highly skilled workers such as engineers and scientists would lower the earnings of the American workers they compete against." Becker acknowledges that "opposition from competing American workers … is understandable," but he insists that a protectionist response would not be "good for the country as a whole."[104]

This difficult issue must be addressed in developing a new national strategy on innovation. To realize its economic potential, the United States must encourage the continued immigration of skilled foreign knowledge workers. But at the same time, the U.S. government must develop policies aimed at reducing possible negative impacts on American knowledge workers. Such policies provide the best argument against protectionism and restrictions on immigration.

Adapting to the Blurred Boundaries of Innovation

Innovation offshoring has created a competitive challenge of historic proportions for the United States. The challenge is driven by profound changes in corporate innovation management as well as the globalization of markets for technology and knowledge workers. U.S. companies, especially in electronics and other high-tech industries, are at the forefront of these developments as they expand their overseas investment in R&D and seek to integrate Asia's new innovation clusters into global networks of production, engineering, development, and research. But Asian governments and firms are playing an increasingly active role as promoters and new sources of innovation.

Innovation offshoring has created substantial benefits for Asian countries. Exposure to leading-edge innovation management approaches and improved access to critical technologies have enabled Asian firms to strengthen their innovative capabilities. Consequently, they have been able to enhance their competitive position in international trade and in the global markets for technology and knowledge workers.

If, as many economists argue, Asia's ability to catch up to the United States has a positive impact on global welfare, the main winners remain the U.S. corporations that employ foreign knowledge workers either at home or overseas. By investing in offshore R&D labs, these companies are able to substantially reduce the cost of U.S.-based scientists and engineers but also gain access to complementary innovative capabilities. Furthermore, innovation offshoring helps U.S. companies to penetrate the growing and increasingly sophisticated markets of Asia.

There is reason for optimism about the U.S. innovation system, but a new national strategy must be implemented

As Asian countries improve their innovative capabilities, the U.S. share of global inputs to the innovation process—such as R&D spending, knowledge workers, and the quantity and quality of scientific literature—will gradually decline. Yet, the policies described in the preceding sections can help to ensure that this does not translate into a sudden weakening of the U.S. innovation system and its capacity to produce significant innovation outputs, such as the quantity and quality of patents and market-defining standards.

There is indeed reason for cautious optimism, but it is imperative that some of the aforementioned policies are implemented as part of a new national strategy. The United States should then be able to sustain and improve its environment for innovation, despite the fact that the growing scope, distribution, and team-oriented nature of innovation will inevitably blur the geographical boundaries within which we try to promote and manage it.

ENDNOTES

1 Mann, *Globalization of IT Services*.

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9 Ernst, "Pathways to Innovation."

10 Granstrand, "Towards a Theory," 27.

11 Fonow, *New Reality*.

12 Hicks, "Growth in Asian S&T Capability."

13 Ernst, "Complexity and Internationalization."

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17 Farrell, Laboissiere, and Rosenfeld, "Sizing the Emerging Labor Market."

18 See Ernst, "Complexity and Internationalization."

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23 Patel and Pavitt, "Large Firms in Technology."

24 E.g., Feldman, "New Economics of Innovation"; Porter and Sølvell, "Role of Geography"; Jaffe, Trajtenberg, and Fogarty, "Knowledge Spillovers."

25 E.g., Dunning, "Globalization, Technology and Space."

26 Ernst, "New Mobility of Knowledge."

27 Ernst, "Global Production Networks and Changing Geography."

28 Cantwell, "Globalization of Technology," 172.

29 Dalton and Serapio, *Globalizing Industrial Research and Development*, 40; Ernst, *From Partial to Systemic Globalization*.

30 Breschi and Lissoni, "Knowledge Spillovers," 991.

31 Kuemmerle, "Home Base and Foreign Direct Investment."

32 Kuemmerle, "Building Effective R&D Capabilities," 66.

33 Granstrand, Patel, and Pavitt, "Multi-Technology Corporations."

34 For details, see Ernst, "New Mobility of Knowledge."

35 Antonelli, *Economics of Information Networks;* Hagstrøm, "New Wine in Old Bottles"; Hagel and Brown, *The Only Sustainable Edge*.

36 E.g., Porter, *Competitive Advantage of Nations*.

37 For details, see Ernst, "New Mobility of Knowledge."

38 For example, Williamson, *Economic Institutions of Capitalism and Markets and Hierarchies*, and Chandler, *The Visible Hand;* Ernst, "The Economics of Electronics Industry."

39 Grove, *Only the Paranoid Survive*.

40 Ernst, "Digital Information Systems."

41 Lazonick, "Stock Options as Compensation."

42 Hyde, *Working in Silicon Valley*.

43 National Science Board, *Science and Engineering Indicators 2004*, 14.

44 U.S. Department of Commerce, *The Digital Economy 2003*, appendix table 2.3.

45 See Arora, Fosfuri, and Gambardella, *Markets for Technology* and Chesbrough, *Open Innovation*. Chesbrough's concept of "open innovation" provides a useful stylized model of this gradual opening of corporate innovation systems. However, the model fails to address explicitly the international dimension, i.e., the development of global innovation networks.

46 Ernst, "Global Production Networks and Changing Geography."

47 Ernst, "Limits to Modularity."

48 National Science Board, *Science and Engineering Indicators 2004*, iv–36.

49 E.g., Campbell-Kelly and Aspray, *Computer*.

50 See Goldstein and Hira, "Spectrum R&D 100." Goldstein and Hira documented IBM's decline among the world's top 50 R&D spenders. In terms of R&D expenditures per employee, Microsoft leads with $141,000, Cisco placed ninth with $92,000, and Intel, 14th with $55,000. IBM lags well behind in 43rd place, spending $16,000 per employee on R&D.

51 Lazonick, "Evolution of the New Economy," 40.

52 Arora, Fosfuri, and Gambardella, *Markets for Technology*, 236.

53 T. Yager, "IBM's Power Grab," infoworld.com/, (accessed December 13, 2005). Tom Yager is technical director of the InfoWorld Test Center.

54 Arora, Fosfuri, and Gambardella, *Markets for Technology*.

55 E.g., Iansiti, *Technology Integration*.

56 Iansiti and West, "Technology Integration."

57 E.g., Ernst, *From Partial to Systemic Globalization* and "Inter-Organizational Knowledge Outsourcing."

58 E.g., Kogut and Zander, "Knowledge of the Firm."

59 E.g., Grindley and Teece, "Licensing and Cross-Licensing."

60 Freeman, *Does Globalization Threaten?* 3.

61 Quoted in National Science Board, *Science and Engineering Indicators 2004*.

62 See Freeman, *Does Globalization Threaten?* 7. Freeman's point is in line with similar arguments by Paul Samuelson in S. Lohr, "An Elder Challenges Outsourcing Orthodoxy," *The New York Times*, September 9, 2005.

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64 J.A. Joerres, Chief Executive Officer, Manpower, Inc., quoted in Boehm, "The Future of the Global Workplace," 18.

65 National Science Board, *Science and Engineering Indicators 2004*, 0–3.

66 Lazonick, "Evolution of the New Economy."

67 NASSCOM-McKinsey, *Extending India's Leadership*.

68 Armbrecht, "Siting Industrial R&D in China."

69 E.g., von Zedwitz, "Foreign R&D Laboratories"; Gassmann and Han, "Motivations and Barriers"; and Li and Zhong, "Explaining the Growth."

70 Ernst and Naughton, "China's Emerging Industrial Economy"; Garcia and Burns, "Globalization and Standard Setting Practice."

71 Santos, Doz, and Williamson, "Is Your Innovation Process Global?" 31.

72 For details, see Ernst, "Global Production Networks and Changing Geography," and "The Economics of Electronics Industry." Since 2002, the author has conducted interviews with a sample of 70 companies and 15 research institutions in the United States, Taiwan, South Korea, China, and Malaysia that are involved in electronic design for integrated circuits as well as systems. The sample contains some of the main global and regional carriers of chip design in Asia. These interviews were conducted at both the parent companies and overseas affiliates of U.S., Taiwanese, and South Korean firms. For Chinese and Malaysian firms, executives were interviewed at the parent companies only. In China, the sample included state-owned enterprises (SOEs), collective enterprises, and private technology firms.

73 Ernst and O'Connor, *Competing in the Electronics Industry*.

74 Similar findings are reported in (1) Armbrecht, "Siting Industrial R&D In China," (2) von Zedwitz, "Foreign R&D Laboratories in China," and (3) Walsh, *Foreign High-Tech R&D in China*. For instance, chips designed by foreign and domestic companies in China were eligible for a 14 percent Value-Added Tax (VAT) tax rebate. This lowers the effective tax rate to 3 percent from the nominal VAT of 17 percent on sales of imported and domestically produced chips. This policy created a powerful artificial cost advantage for domestically designed chips and was later abandoned under pressure from the U.S. government.

75 This supports earlier findings in the literature. For example, see Shen, *The Chinese Road to High-technology;* Lu, *China's Leap into the Information Age*; Naughton and Segal, "Technology Development in the New Millennium"; Ernst, Ganiotsos, and Mytelka, *Technological Capabilities;* Ernst and O'Connor, *Competing in the Electronics Industry;* Ernst, *What are the Limits?;* and Ernst, "Inter-Organizational Knowledge Outsourcing."

76 Rowen, *Engineering the Complex SOC;* Martin and Chang, *Winning the SoC Revolution;* Baldwin and Clark, *Design Rules*.

77 Ernst, "Complexity and Internationalization."

78 IBS, *Analysis of EDA Expenditures*, 42.

79 Saxenian, "The Silicon Valley Connection."

80 UNCTAD, *Survey on Internationalization of R&D*, Table 1.

81 National Research Council, *Measuring Research and Development*.

82 Freeman, *Does Globalization Threaten?* 25.

83 For a critical assessment, see Unger, "Fallout from *Regulation FD*." L.S. Unger is one of the dissident commissioners of the U.S. Securities and Exchange Commission who voted against *Regulation FD*.

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86 Cohen and Merrill, *Patents in the Knowledge-Based Economy;* Merrill, Levin, and Myers, *A Patent System for the 21st Century*.

87 von Hippel, *Democratizing Innovation*.

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92 Michael D. Johnson, in a letter to the *Financial Times*, January 18, 2006, in response to the above article by Segal and Yochelson.

93 Paul Samuelson calls this "brain [being] applied to making money grow" in his jacket review of Emmanuel Derman's fascinating book, *My Life as a Quant: Reflections on Physics and Finance*. The book chronicles the author's transition from theoretical physicist to expert finance executive at Goldman Sachs and Salomon Brothers. See Derman, *My Life as a Quant*.

94 National Science Board, *Science and Engineering Indicators 2004*, 37.

95 Norman, *The Invisible Computer*, 3.

96 Lester and Piore, *Innovation*, 9.

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101 American Electronics Association, *Losing the Competitive Advantage?* 24.

102 E.g., Freeman, *Does Globalization Threaten?*

103 Hira and Hira, *Outsourcing America*, 179.

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AUTHOR INFORMATION

Dieter Ernst is a senior fellow in the Economics Study Area of the East-West Center Research Program. Ernst co-chairs an advisory committee of the U.S. Social Science Research Council (SSRC) that is focused on developing a new program on Innovation, Business Institutions, and Governance in Asia. He also serves as scientific advisor to several institutions, among them the Organization for Economic Cooperation and Development (OECD), the World Bank, the Asian Development Bank, and various United Nations (UN) agencies, especially the UN Conference on Trade and Development (UNCTAD) and the UN Industrial Development Organization (UNIDO).

Ernst is a former senior advisor to the OECD, Paris; a former research director, Berkeley Roundtable on the International Economy (BRIE) at the University of California at Berkeley; and a former research professor at the Copenhagen Business School. He holds a Ph.D. in economics from Universitaet Bremen.

His current research focuses on offshore outsourcing through global production and innovation networks, global markets for knowledge workers, and the implications of offshore outsourcing for industrial and technology policies. Ernst has published numerous books and articles in leading journals on information technology, globalization, and economic development. His recent and forthcoming books include *Innovation Offshoring and Global Knowledge Networks* (forthcoming), *International Production Networks in Asia: Rivalry or Riches* (2000), and *Technological Capabilities and Export Success: Lessons from East Asia* (1998). The bibliography also includes an extensive list of his recently published works.

Contact address:

Research Program
East-West Center
1601 East-West Road
Honolulu, Hawaiʻi 96848-1601

Telephone: (808) 944-7321
Facsimile: (808) 944-7399
Email: ErnstD@EastWestCenter.org

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Most analysts agree that critical ingredients for economic growth, competitiveness, and welfare in the United States have been policies that encourage strong investment in research and development (R&D) and innovation. In addition, there is a general perception that technological innovation must be based in the United States to remain a pillar of the American economy. Over the past decade, however, the rise of Asia as an important location for "innovation offshoring" has begun to challenge these familiar notions. Based on original research, this report demonstrates that innovation offshoring is driven by profound changes in corporate innovation management as well as by the globalization of markets for technology and knowledge workers. U.S. companies are at the forefront of this trend, but Asian governments and firms are playing an increasingly active role as promoters and new sources of innovation.

Innovation offshoring has created a competitive challenge of historic proportions for the United States, requiring the nation to respond with a new national strategy. This report recommends that such a strategy include the following elements:

1. Improve access to and collection of innovation-related data to inform the national policy debate;

2. Address "home-made" causes of innovation offshoring by sustaining and building upon existing strengths of the U.S. innovation system;

3. Support corporate innovation by (1) providing tax incentives to spur early-stage investments in innovation start-ups and (2) reforming the U.S. patent system so it is more accessible to smaller inventors and innovators; and

4. Upgrade the U.S. talent pool of knowledge workers by (1) providing incentives to study science and engineering, (2) encouraging the development of management, interpretive, cross-cultural, and other "soft" capabilities, and (3) encouraging immigration of highly skilled workers.

East-West Center
1601 East-West Road
Honolulu, Hawai'i 96848-1601

Telephone: (808) 944-7111
Facsimile: (808) 944-7376
Email: ewcinfo@EastWestCenter.org
Website: www.EastWestCenter.org

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