Introduction

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The causes and consequences for U.S. competitiveness and living standards of innovation by foreign nations and firms have been long-standing topics of scholarly and policy debate within the United States. During the 1960s and 1970s, much of this debate focused on U.S. multinational firms' investment in offshore research and development (R&D) and production facilities, most of which were located in other industrial economies. Concern was expressed that the transfer of technology by U.S. corporations through their offshore R&D and manufacturing investments would contribute to the growth of foreign competitors in these and other industries and reduce domestic employment opportunities. The debates of the 1980s and early 1990s adopted a slightly different tone, emphasizing the growth of foreign competitors in industries such as automobiles and semiconductors whose innovative performance and high-quality products threatened the viability of U.S. firms (including multinational U.S. firms) and entire industrial sectors. These debates were concerned less with the offshore transfer of U.S. technological capabilities than with the threat posed by foreign firms' competitive strengths.

A previous volume (*U.S. Industry in 2000: Studies in Competitive Performance*) released by the National Academies' Board on Science, Technology, and Economic Policy in 1999 argued that much of the pessimism of the 1980s and 1990s over U.S. industrial competitiveness proved to be exaggerated or misplaced. U.S. firms in a number of industries developed new business models and new products, which enabled them to address competitive threats with considerable success. In some cases, the responses of U.S. firms relied on their position within a large domestic market of innovative users who proved to be important sources for new ideas and products. In other cases, improvements in U.S. competitive and innovative performance relied on the robust domestic "R&D infrastructure" comprising industrial, governmental, and university research facilities, much of which had benefited from large federal investments spanning the post-1945 period. U.S. firms and consumers alike also benefited from low-cost imports of some products, such as personal computers and components that were critical inputs for the innovation and restructuring processes described in this volume.

A more recent wave of concern over U.S. competitive prospects in the 21st century combines elements of all of these previous debates. The actions of many U.S. firms (not all of which can be considered multinational by any conventional definition) to "outsource" activities formerly undertaken by U.S.-based professional, scientific, and engineering employees have raised widespread popular concerns over the erosion of employment opportunities in occupations and industries (including many service industries) that formerly were minimally exposed to foreign competition. At the same time, the growth of innovative and manufacturing capabilities in countries such as China, India, South Korea, and Taiwan has raised concerns over new sources of competition for U.S. firms. A 2006 study of U.S. competitiveness and innovative performance phrased these concerns as follows:

> . . . the committee is deeply concerned that the scientific and technological building blocks critical to our economic leadership are eroding at a time when many other nations are gathering strength. We strongly believe that a worldwide strengthening will benefit the world's economy—particularly in the creation of jobs in countries that are far less well-off than the United States. But we are worried about the future prosperity of the United States. Although many people assume that the United States will always be a world leader in science and technology, this may not continue to be the case inasmuch as great minds and ideas exist throughout the world. We fear the abruptness with which a lead in science and technology can be lost—and the difficulty of recovering a lead once lost, if indeed it can be regained at all. (National Research Council, 2006, Executive Summary, p. 2)[1]

A central issue in the long debate over U.S. competitiveness that is briefly summarized above is the processes through which industrial firms in the United States and other economies create innovative new products and processes. What has changed in the global and U.S. domestic economies to transform the near euphoria in popular evaluations of U.S. economic and innovative performance during the "New Economy" of the late 1990s to the concerns expressed by

[1]A similar sentiment may be found in Freeman (2005): "But the US will also face economic difficulties as its technological superiority erodes. What is good for the world is not inevitably good for the U.S. The group facing the biggest danger from the loss of America's technological edge are workers whose living standards depend critically on America's technological superiority. The decline in monopoly rents from being the lead country will make it harder for the US to raise wages and benefits to workers. The big winners from the spread of technology will be workers in developing countries, and the firms that employ them, including many U.S. multinational corporations" (p. 27).

the blue-ribbon panel cited above? In particular, what characteristics of the innovation-related activities of U.S. and non-U.S. firms have changed since the late 1990s so significantly to trigger these concerns? On the other hand, recognizing that many elements of this debate are not new but have been widely shared since the 1960s, what aspects have not changed in the innovation-related competition in which U.S. and foreign firms find themselves engaged? How well are scholars or policy makers able to measure any such change at a sufficiently fine-grained level of analysis to inform such debates? Finally, what are the implications for public policy of change in the structure (especially globalization) of U.S. firms' innovation-related activities? This volume examines these questions by providing detailed studies of structural change in the innovation process in 10 manufacturing and service industries.

Any study of issues related to innovation and competitiveness must address the widely held view that "firms compete, nations don't." In other words, the innovation-related and employment consequences of global competition are the result of private-sector investment and management decisions—public policy is of little importance. Just as it distorts reality to claim that international economic competition is solely a matter of competition among governments, the claim that private managers' decisions are all that matter is also an oversimplification, particularly in light of the evidence presented in many of the chapters in this volume. The international performance of firms, including multinationals, is affected by policy and other economic conditions in their home countries. And this link is especially strong for firms' innovation-related activities, which rely on a complex infrastructure of public and private institutions devoted to knowledge creation and transmission, personnel training, and other activities. Indeed, one of the most striking findings in many of the chapters in this volume is the extent to which the inventive activities of firms in many knowledge-intensive industries remain concentrated in their home countries. Simply put, both firms and nations matter.

THE STEP BOARD STUDY

Recognizing that the debate over the international transfer of technological and innovative capabilities and potential loss of U.S. competitiveness is a long-running one, the Science, Technology, and Economic Policy (STEP) Board of the National Academies undertook a study in 2006-2007 of the changes in the structure of the innovation process that are associated with shifting perceptions of the competitive outlook for U.S. firms and domestic employment, especially in professional and engineering occupations.

The STEP Board study examined 10 industries: personal computers, software, semiconductors, flat panel displays, lighting, pharmaceuticals, biotechnology, logistics, venture capital, and financial services. The choice of industries reflected several factors: (1) coverage of knowledge-intensive industries that have been the focus of many expressions of concern over waning U.S. technological strength; (2) inclusion of service industries, which historically have received little attention in debates over foreign competition and innovation; and (3) the willingness of scholars who have conducted extensive research on these industries to examine the issues of change in the structure and globalization of innovation-related activities. Reflecting the study organizers' interest in highlighting similarities and differences across industry-level studies, we drew on scholars affiliated with the Industry Centers established with initial financial support from the Alfred P. Sloan Foundation.

The following is a summary of the findings of each industry study.

Personal Computing

The personal computer (PC) industry now operates as a global network of independent suppliers of systems, components, peripherals, and software. Although the pace of innovation in the industry is rapid, its character now is largely incremental because of the dominance of the "Wintel" PC architectural standard. One important future challenge is the integration of the PC with the proliferating array of consumer devices that "orbit the user" and provide computing and communication capability (e.g., PDAs, phones, music players).

The global division of innovation-related activities within the industry is characterized as follows: component-level R&D (concept design and product planning) is performed in the United States and Japan; applied R&D and development of new platforms (particularly notebook computers) take place in Taiwan; and product development for mature products (mainly desktop computers) and a majority of production and sustaining engineering are performed in China.

U.S. PC firms have benefited from the international division of labor in innovation that has supported rapid innovation and quicker integration of new technologies into new products. The growing demand for smaller, more mobile products plays to U.S. firms' strengths in product architecture and early stage development. The shift in production activities away from the United States has pulled new product development activities to Asia, but design jobs, which are relatively few in number, are expected to remain largely in the United States.

Software

U.S. firms dominate global trade in both packaged software products and software services, although their leadership position is weakening in software services. Important non-U.S. providers of software services are located in India (software services), Ireland (software logistics, localization, and development), and Israel (product development and R&D). Despite some change in the location of leading providers of software services, there has been relatively little change in the location of new software product development. Inventive software development activity (at least as measured by patents) is concentrated in the United States and is controlled by U.S. firms. Some inventive activity by U.S. firms has shifted abroad but represents a relatively small share of the overall inventive activity of U.S. firms.

The importance of repeated interaction between software developers and users is especially important in the early stages of complex projects, and the enormous size and sophistication of the U.S. market for software and services means that the United States is likely to retain its dominant role in this industry for some time to come. Nonetheless, some software development activities will continue to move to offshore sites characterized by lower labor costs and high-quality manpower. The chapter highlights the importance for the future U.S. software industry of federal support for computer science R&D in industry and academia in the face of continued upgrading of the capabilities of offshore sites for R&D and product development.

Semiconductors

Significant structural change occurred in the U.S. semiconductor industry during the 1990s. Among the most important changes were shifts in markets for semiconductor component applications, changes in the location of production and geographic structure of markets for semiconductor components, and increased vertical specialization in industry structure. Despite these changes, the contributions of "offshore" sites to U.S. semiconductor firms' innovation-related activities remain surprisingly modest. For example, process R&D remains predominantly "homebound"—concentrated in global semiconductor firms' home countries. The patenting activity of U.S. and non-U.S. semiconductor firms alike is similarly dominated by domestic inventive activity. The innovation-related activities of global firms in this industry remain remarkably "nonglobalized," even in the face of greater international flows of capital and technology, far-reaching change in the structure of semiconductor manufacturing, and significant shifts in the structure of demand.

The vertically specialized industry structure that now characterizes the semiconductor industry has enabled U.S. firms specializing in design and marketing of semiconductor components to access global production networks and grow rapidly. Nevertheless, continued growth in production capacity and design capabilities in Southeast Asia is likely to result in expanded offshore product design and development activity by U.S. firms and the entry of new firms based in this region.

Flat Panel Displays

The flat panel display industry originated in the United States, but production-related activities quickly migrated to Japan, followed by Korea and Taiwan, and now are expanding in China. Innovation in the flat panel display industry has been driven by periodic shifts to larger "form factors" (i.e., larger screens), which affect the design of new products and new manufacturing processes. Innovative activity has tended to follow production investment in the industry because of the high demand for process innovation. The migration of production away from the United States means that U.S. firms play a limited but important role in the innovation process, primarily as suppliers of specialized components (e.g., glass substrates). The innovation-related activities of these U.S. firms remain concentrated in the United States, although all of these firms have invested in offshore R&D and related activities that are located near major customers.

Lighting

The structure, characteristics, and location of innovation in lighting contrast with those of predecessor lighting technologies. The traditional lighting industry, which relied on incandescent, gas-discharge, and fluorescent technologies, was dominated by a three-firm oligopoly (GE, Philips, and OSRAM) based in the United States and Europe. All three firms still operate global production networks for the manufacture of traditional lighting products, but they face increased competition from low-cost Southeast Asian producers in traditional lighting products. Moreover, the growth of markets for lighting technologies based on light-emitting diodes (LEDs) has begun to transform the competitive balance of the industry. The three dominant firms were slow to enter the LED market and have subsequently utilized joint ventures and acquisitions for technological catch-up, but they have failed to achieve market dominance in this technology.

Lighting innovation, which historically was dominated by the U.S. and European R&D facilities of the leading firms, has shifted to Southeast Asia. An analysis of patenting in lighting indicates that Japanese and U.S. firms hold modest leadership positions in inventive activity, but their lead is shrinking as Taiwanese and other Southeast Asian companies improve their R&D capabilities. Most global firms have established Asian-based manufacturing, engineering, and R&D operations, principally in Japan and Taiwan. The lighting industry also has developed a vertically specialized structure, with firms specializing in R&D, production, packaging, and other functions within the value chain.

Pharmaceuticals

The structure of the U.S. pharmaceutical industry has been transformed since 1990 by the rise of biotechnology and intensified competition from global generic manufacturers. Innovative activity in the industry (measured in terms of industry-financed R&D investment and patenting) is concentrated in the United States, some European Union countries, and Japan. U.S. pharmaceutical firms have been leading investors in offshore R&D, which has been concentrated in high-income economies, since the 1980s. Important economic factors, such as localized knowledge spillovers, intellectual property protection, and government policies related to price regulation, state procurement of drugs, and health and safety regulation, have helped to reinforce this geographic concentration of innovative activity. Nonetheless, increasing vertical specialization within the industry, as well as improvements in the scientific and engineering capabilities of nations such as India, has been associated with shifting some innovation-related activities to offshore sites. Thus far, the innovation-related activities that have experienced some movement include manufacturing process innovation and clinical trials management.

In some respects, the trends in offshore movement of pharmaceutical R&D resemble those in the U.S. software industry in the early 1990s. U.S. firms continue to dominate the innovative efforts of the industry, a position that has been reinforced considerably by large public investments in biomedical R&D in academic and government research facilities. The U.S. market is also an attractive site for product innovations, given the minimal price controls that characterize it at present.

Biotechnology

Although it has attracted a great deal of attention from policy makers, investors, and entrepreneurs, the U.S. biotechnology industry employs a relatively small number of individuals overall, and even fewer scientists and engineers. The industry consists of several distinct segments that span biomedical, industrial, and agricultural biotechnology. Development of the industry has been dominated by biomedical applications, for which prices and profits tend to be greatest. The biomedical segment is concentrated in particular regions in the United States and Western Europe, reflecting the importance of the interaction of biomedical biotechnology firms with science-based university research. Although many countries around the world now "host" a biotechnology industry (of varying importance), biotechnology activity within most of these nations is often centered in a single metropolitan area. Nevertheless, an increasing number of distinct locations in the United States and an increasing number of countries support modest to significant biotechnology activity.

Vertical specialization has played an important role in the development of the biomedical segment in particular, since many new firms in this segment serve as "research boutiques," conducting R&D in new drugs that are subsequently developed for commercial purposes by larger pharmaceutical firms. The biotechnology industry itself has experienced considerable vertical specialization, and (as in other industries examined in this volume) the development of a vertically specialized structure has tended to support the globalization of innovation-related activities. Based on its large academic and public biomedical R&D infrastructure, however, the United States remains the dominant location for advanced R&D and product development in the industry, and the growth of offshore R&D and related activities is likely to have a minor impact on U.S. employment in this industry for the foreseeable future.

Logistics

The logistics industry manages the planning and control of the flow and storage of goods, services, and related information between the point of production and the point of consumption. The industry has expanded rapidly since 1990, in parallel with the globalization of manufacturing, and now includes a large number of specialized firms. Innovation in logistics frequently occurs in response to new customer requirements, and this process in many respects resembles the "co-invention" activity that typifies innovation in computer software. Advances in supporting technologies, such as information technology and communications, are another important source of innovation in logistics.

Close interaction between the developers and users of logistics services is essential to innovation, and the global spread of logistics networks has been associated with growth in the offshore innovation-related activities of U.S. and non-U.S. logistics firms. Nevertheless, analysis of logistics-related patents indicates that U.S. logistics firms specializing in information technology (IT)-related software and services remain dominant within the industry. As the logistics industry develops a more global structure, the role of governments in creating and enforcing intellectual property protection, in reducing trade barriers and standardizing import rules, and in supporting the training of managers, engineers, and technicians capable of furthering innovation will grow in importance.

Venture Capital

The venture capital (VC) "industry" in its modern form emerged in the United States during the post-1945 period. Although the industry now operates globally, U.S. firms remain dominant. Globalization of the VC industry has occurred through cross-border partnerships, the establishment by U.S. VC firms of overseas offices, and expansion within the United States by foreign VC firms. This process is likely to continue as countries develop clusters of technological expertise that attract the attention and investments of VC firms throughout the global economy, as multinational corporations acquire more foreign startups, and as financial markets throughout the world develop sufficiently to support the liquidation by venture capitalists of their investments. Indeed, in some important respects, globalization of innovation in VC reflects the growth of innovation-related entrepreneurship in other economies.

The primary focus of investments by U.S. and non-U.S. VC firms has been the IT sector, including semiconductor, computer software, computer hardware, and related industries. Indeed, the historic strength and innovative dynamism of the U.S. IT sector is one factor behind U.S. VC firms' dominant position in the industry. Although the globalization of VC has not had negative consequences for the U.S. innovation system, U.S. VC firms will continue to expand their offshore activities and support the creation of foreign startups that compete directly against U.S. firms in the IT and other high-technology sectors. The effect of these investments will be strongly influenced by most economies' evolving regulatory and legal systems.

Financial Services

The rapid expansion in offshore investment in business process support by U.S. financial services firms has led to increased innovation within these offshore locations by subsidiaries of U.S. firms as well as independent providers of specialized services. The growth of vertical specialization within the global financial services industry also has affected the structure of innovation-related activities. There are strong complementarities between process and product innovation in this industry, but the offshore movement (mainly to Asian countries) of "back-office" functions has supported increased offshore innovation in these processing functions. Firms based in high-income markets such as the United States and Europe remain the primary sources of product-oriented "customer-facing" innovations, but market-mediated interaction between end users and providers is less important to the process innovation activities of many of these offshore sites.

WHAT HAS CHANGED SINCE 1990?

These summaries of structural change in the innovation-related activities of the industries examined in the volume highlight four broader trends: (1) the growth of innovative capabilities in a number of foreign nations that 30 years ago were classified as "developing economies," (2) the growth of sophisticated manufacturing and services-production activities in these and other economies, (3) the growth of demand for cutting-edge technologies (particularly in IT) in markets outside of the United States, and (4) the growth of "vertical specialization" in many knowledge-intensive industries. A discussion of each of these trends follows.

Improved Innovative Capabilities in New Regions of the Global Economy

The first and perhaps most important of these trends is the growth of innovative capabilities in countries such as China, India, Taiwan, and South Korea, none of which were active in R&D or product development for global markets during the 1960s and 1970s. In some of these countries, indigenous firms or subsidiaries of foreign firms are performing fundamental research. In most of them, improvements in innovative capabilities have enhanced the ability of these countries to contribute to the design and development of advanced products, including those in service-based industries such as financial services and logistics. Particularly in India and China, advances in regional innovative capabilities have been associated with growth in domestic scientific and engineering workforces.

With the important exception of India, whose role in the production of software and services has assuredly expanded, the transformation of these countries' innovative capabilities has been linked to growth in the domestic manufacture (in some cases, in foreign-owned facilities) of products for global markets in industries ranging from PCs to automobiles. And just as has been true of innovation in the industrial economies, the growth in innovation-related activities within countries such as India, China, and Taiwan has been associated with regional concentration and agglomeration—Bangalore, Shanghai, and Hsinchu are examples of regional "high-technology" agglomerations in India, China, and Taiwan, respectively.

Expansion of Production Activities Outside of the United States

A second factor in the transformation of the innovation processes in the industries discussed in this volume is the expansion of production activities outside of the United States in these and other regions. The extent and timing of this expansion of offshore production vary among industries (e.g., offshore production is hardly a new feature of the automobile industry, but is less important in biotechnology). In a number of industries, however, ranging from semiconductors to flat panel displays and PCs, U.S. firms rely on sites outside of the United States (through ownership or contracts) for a growing share of their production requirements. Much of this offshore expansion in manufacturing activity has occurred in Asia and Southeast Asia, particularly in China, Taiwan, and South Korea. In the flat panel display industry, growth in Asian production by U.S. firms and the entry into production by Asian firms have "pulled" many innovation-related activities (e.g., process innovation) to Asian sites. Increased offshore manufacturing by U.S. semiconductor firms, by contrast, has had more modest consequences for the location of innovation-related activities. There is little evidence of shifts to offshore locations in the patenting activities of U.S. (or non-U.S.) semiconductor firms, and no evidence of offshore shifts in the location of process-innovation activities of U.S. semiconductor firms.

Growth in global "production networks" in many of the industries discussed in this volume has provided a powerful impetus for the expansion of logistics that has in turn spurred and depended on significant innovation in the logistics industry. Expanding offshore production and product-development networks in industries such as semiconductors and software also has accelerated growth in foreign nations' VC industries.

The Changing Profile of Demand for Advanced Products in Foreign Markets

Yet another influence on the movement of product design and development activities away from the United States in industries such as software, semiconductors, and PCs is interregional shifts in the scope and sophistication of consumer demand. Consumer markets for wireless and digital devices in countries such as South Korea, for example, are growing more rapidly than are similar markets in the United States. Equally important is the fact that many consumers in these markets (including firms producing advanced electronic-systems products) demand more advanced applications than is true of consumers elsewhere in the global economy. Users play a crucial role in demanding and in some cases developing or "co-inventing" new applications in the aforementioned industries, as well as in logistics. Firms seeking to exploit and develop new applications for these dynamic user-driven markets typically must locate a portion of their product development and design activities within these markets. In industries such as semiconductors, U.S. firms' offshore design activities rely on close contacts with local firms who design and produce the new consumer products that incorporate advanced semiconductor components.

The "product cycle" model that influenced academic analysis of U.S. firms' offshore manufacturing and R&D activities during the 1960s (Vernon, 1966) posited that U.S. firms developed and introduced their most advanced products within their domestic market before marketing and (eventually) manufacturing these products offshore. Although product demand in a number of the industries examined in this volume remains important, several of the most advanced markets in these industries now are located in foreign economies and, therefore, attract increased investment by U.S. firms seeking to develop advanced products. In effect, the product cycle has been reversed, with important implications for the location by U.S. firms of their product development activities.

Increased "Vertical Specialization"

Structural change in the industries examined in this volume has influenced the shifting structure and location of innovation-related activities. Perhaps the most pervasive and important type of structural change, one that is observed in industries ranging from PCs to pharmaceuticals and biotechnology, is vertical specialization—the development of an industry structure populated by firms that specialize in one or a limited set of activities who contract with other firms that specialize in different activities within the industry. For example, one group of firms in the pharmaceutical industry now focuses on drug discovery and contracts with other firms for drug development (e.g., clinical trials) and post-approval marketing. In semiconductors, manufacturing "foundries" collaborate on a contractual basis with "fabless" semiconductor firms that specialize in design and marketing of semiconductor components. This type of contract-based collaboration among specialized firms differs considerably from the operations of firms that are vertically integrated in all functions ranging from R&D through manufacturing to marketing.

In many industries, vertical specialization has developed in parallel with (and in many cases has accelerated) global shifts in production activities. The manufacturing specialists in semiconductors are largely located in Asia, whereas fabless semiconductor firms remain largely based in the United States. Similarly, the systems architecture, software operating systems, and semiconductor components within PCs are designed in the United States, but almost all production activity is located offshore and managed by firms not affiliated with the U.S. semiconductor or software enterprises. Moreover, the offshore manufacturers of PCs rely on specialized suppliers of components ranging from disk drives to displays.

Vertical specialization thus far has had varied effects on the location of innovation-related activities in the industries discussed in this volume. Although flat panel display production is located almost entirely outside of the United States, U.S. firms retain important roles in technology development (including investing in U.S.-based R&D) as suppliers of specialized inputs and equipment. In PCs, vertical specialization has been associated with the geographic separation of manufacturing from high-level design activities. Although some semiconductor design activities have migrated to the East Asian sites where the bulk of specialized semiconductor producers are located, U.S. sites retain an important role in advanced design activities. The location of U.S. pharmaceuticals and biotechnology R&D does not appear to have shifted in response to growing offshore drug production and marketing activities.

In some industries, the factors determining the location of advanced R&D activities seem to differ significantly from those influencing the location of manufacturing. In semiconductors and pharmaceuticals, vertical specialization has supported the formation of new U.S.-based firms whose business models rely on collaboration with offshore manufacturers. Vertical specialization also has aided the growth of innovation and globalization in financial services and logistics by facilitating the complex web of transactions that underpin the structure of these industries. But in other industries, such as lighting, shifts in the location of production have had significant implications for the location of innovation-related activities.

WHAT HAS NOT CHANGED?

Although many aspects of the innovation process in the industries examined in this volume (as well as many others) have undergone significant change since 1990, the broad economic and policy challenges associated with such structural change have changed little. In most of these industries, U.S.-based firms continue to perform the majority of their (most advanced) R&D within the United States. Inventive activity, as measured by the location of inventors for U.S. patents filed by U.S.-based firms, remains remarkably "homebound" in industries such as biotechnology, pharmaceuticals, semiconductors, and software.[2]

[2] Indeed, patent-based indicators suggest that the inventive activity of foreign-based firms in these industries also remains concentrated in their home countries.

Nevertheless, in other industries, a growing share of the R&D and inventive activity at the technological frontier now appears to be located outside of the United States. In the lighting and flat panel display industries, non-U.S. firms and nations have become more prominent innovators since 1990. Moreover, even within industries such as software or semiconductors, in which the inventive activity of U.S.-based firms appears to be concentrated in the United States, a substantial (and poorly measured) portion of the design and development of new products has moved offshore, either to exploit lower labor costs or to collaborate more closely with innovative users. As we noted earlier, however, the ability to exploit offshore innovative talent has supported the entry and growth of numerous U.S. firms pursuing new business models and technology strategies.

Thus, economic change has affected the structure of the innovation process in all of the industries studied. The characteristics of structural change in virtually all of these industries resemble those emphasized in the analyses of U.S. competitiveness highlighted earlier: Industries and activities in which U.S. workers (defined in this case to include scientists and engineers) add less value are the most vulnerable to foreign competition and the most likely ones to move to foreign sites. The improved capabilities of scientists and engineers in many of these foreign locations, the identity of these locations themselves, and the changing outlook of demand and growth in the U.S. and foreign markets, however, may be causing more rapid shifts in competitive advantage and affecting a broader range of activities, including innovation-related activities, than in earlier decades. Nevertheless, the fundamental conclusion remains unchanged: For U.S. firms, consumers, and workers to profit from the expanding opportunities in the global economy, their innovative and productivity performance must continue to improve; the U.S. economy must remain open to inflows of goods, technology, and capital; and the infrastructure underpinning the domestic U.S. R&D "system" must remain highly innovative and attractive as a site for investment by U.S. and non-U.S. firms alike.

Another important element of continuity that contemporary analyses of innovation and globalization share with earlier discussions of this topic is the poor quality of the data on which they rely. As the previous STEP Board study (*U.S. Industry in 2000*) noted, restructuring in the domestic and international R&D systems means that conventional R&D investment data are less reliable as a guide to structural change in the innovation process. The R&D investment data collected by the National Science Foundation (NSF) and other public statistical agencies in the United States and other industrial economies arguably do not include a number of the activities (e.g., product design, or spending by firms on acquisitions as a means of gaining access to new technologies or capabilities) that play a central role in the innovation process of the 21st century. Moreover, the NSF data provide limited information on the international dimensions of R&D investment by U.S. and non-U.S. firms. These problems with the R&D investment data have been the subject of a number of studies by the STEP Board, the National Research Council, and other expert panels, but the fact remains that much of the analysis of globalization in the innovation process is hampered by limited, dated, and imperfect data and indicators. These data limitations are especially serious for service-based industries, which have expanded their investment in R&D and offshore production significantly since 1990.

A number of the chapters in this volume rely on patent data to supplement the limited R&D investment data available for their industry. Patent data have a number of advantages, including their disaggregation into specific technology classes, and their reporting of both the assignment and geographic location of the patent owner(s). Nevertheless, patents have important disadvantages as well. They measure inventive activity, which is an important input to the overall process of commercial innovation, but do not measure the output of the innovation process. The coverage by patents of even inventive activity within different industries and technology classes also varies, as does their commercial and economic value among fields of invention. Equally important is the fact that the grant of a patent follows a period of review of the patent application that typically takes at least 18 months and frequently requires 3 to 5 years. Therefore, patent data provide a "retrospective" measure of inventive activity occurring as many as 5 years ago, and this inventive activity itself results from investments in R&D and other activities made still earlier. Although patent data represent a valuable additional set of indicators of innovation-related activities in a much more complex global economic environment, their limitations must be kept in mind.

Yet another area in which the quality of available data makes it difficult to draw definitive conclusions is the effects on domestic scientific and engineering employment from the globalization of innovation-related activities that is occurring in many of these industries. Data on industry-wide employment trends for scientists and engineers in many of these industries (e.g., logistics, venture capital, PCs, software) do not exist, reflecting the complex structure of the industries and the outdated structure of publicly available data on industry employment. Moreover, the central topic of these chapters is not shifts in the location of these industries but shifts in the location of specific functions within these industries. And many of the trends described in these chapters (e.g., greater reliance on advanced information and communications technologies, vertical specialization) facilitate the geographic separation of different activities within industries, rather than the relocation of entire industries.[3]

[3]The distinction is an important one, since the gloomy predictions made by Freeman (2005) and others assume that the United States will lose its historic dominance in knowledge-intensive industries as a result of the growing technological and scientific capabilities and workforce in nations such as India and China. What these chapters indicate is that some specific functions (e.g., product manufacture, software coding, product development) may shift to offshore locations. But these shifts need not pull other knowledge-intensive activities in their wake, and in some cases (as in semiconductors) these shifts in location create opportunities for the growth of new firms in the United States. The Freeman predictions cannot be dismissed, although Branstetter and Foley (2007) present a more skeptical view of the current level of MNE R&D and innovation within China. Nevertheless, the trends described in

The chapters in this volume on semiconductors, software, and PCs all conclude that the employment consequences for scientists and engineers from the restructuring of innovation-related activities thus far are modest and not clearly negative or positive. Indeed, leading U.S. firms in these IT-related industries consistently complain about the lack of sufficient immigration visas to hire foreign-born engineers needed to address shortages (Lohr, 2007).[4] It is also difficult if not impossible to separate the "contributions," negative or positive, to scientific and engineering employment of the globalization of an industry's innovation-related activities from myriad other factors.

Overall, therefore, the data underpinning the conclusions of all of the chapters in this volume provide a clearer understanding of the past than they do of the future. Although the nature of the innovation process is such that the near-term future is not likely to differ radically from the recent past, the fact remains that the data underpinning detailed industry studies such as these provide a limited foundation for forecasts.

POLICY ISSUES AND CHALLENGES

The fundamental challenges for policy created by the processes of globalization described in this volume have changed little from those described in studies of this topic that date back to the 1960s and 1970s. To preserve and expand employment in the functions and professions that benefit from the globalization of innovation, the United States must sustain the high levels of innovative performance that have supported the competitiveness of U.S. industry and have made the United States a major destination for R&D investment from foreign firms. Among other things, this goal means that support for the "R&D infrastructure" that decades of public and private investment have created must be strengthened.

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this volume reflect a different process of economic change. Indeed, it is highly plausible that stronger scientific and engineering capabilities in India and China will produce effects similar to those observed after Japanese and European "convergence" with U.S. levels of innovation-related expertise, as Bhagwati et al. (2004) point out: "When the revival of Europe and Japan brought their skill levels closer to those of the United States, the gains from trade induced by 'factor endowment differences' were increasingly replaced by gains from 'intraindustry' trade; for example, the United States now specializes in high-end chips such as Pentium, while leaving more standard semiconductor chips to foreign producers. Similarly, we can confidently expect 'intraservice' and 'intraindustry' trade to grow between the United States on the one hand and India and China on the other as the latter acquire more skills" (p. 108). Alternatively (and equally plausibly), one may observe growth in "intrafunction" trade within such activities as new product development, based on the same factors.

[4] H-1B visas are given to foreign workers with high-technology skills or in specialty occupations by the Citizenship and Immigration Services Agency. U.S. companies seek H-1B visas on behalf of foreign scientists and engineers to fill hiring shortfalls, but Congress mandates that the Agency cap the number of visas granted to 65,000. Some claim that U.S. H-1B visa policies are counterproductive and detrimental to U.S. technological and economic competitiveness, while others see them as critical to protecting domestic workers.

This infrastructure has supported investment and innovation by U.S. and foreign firms in the industries examined in this volume, as well as others, and has yielded great benefits to U.S. consumers.

Other developing and developed countries now recognize the importance of such an infrastructure and, in many respects, are emulating U.S. policies by making similar public and private investments. A failure by the United States to maintain its commitment to the strength and quality of its public and private R&D infrastructure could limit the benefits for U.S. citizens of the globalization of innovation-related activities described in this volume. Here, as elsewhere, the competitive dynamics should not be seen as a "zero-sum" competition—U.S. citizens benefit from higher levels of R&D investment by foreign governments, just as foreign citizens have benefited from U.S. public R&D investment. But the mobility of innovation-related activities means that the United States must remain an attractive site for these activities by U.S. and non-U.S. firms in order to maintain employment opportunities for skilled personnel.

Beyond sustaining this infrastructure, however, public policies must ensure that government R&D investments yield the highest possible public returns. Achieving this goal means that university-industry research collaboration should be supported by public policy, without imperiling the critical role of U.S. universities as educational institutions that produce world-class scientists and engineers. Any obstacles to such collaboration imposed by shortsighted university patenting and licensing policies also should be reviewed critically by university administrators, industry managers, and policy makers.[5] As Thursby and Thursby (2006) note, one of the most important influences on the location of multinational corporations' advanced scientific research facilities is proximity and access to university researchers. U.S. universities, like U.S. firms, face growing competition from foreign institutions for industry-supported collaborative R&D and must adjust their policies toward intellectual property management accordingly. Policies that limit federal support for academic research on politically sensitive topics such as embryonic stem cells also reduce the attractiveness of U.S. universities as research collaborators and therefore weaken the "magnetic force" of these important institutional assets for R&D investment in the United States from foreign sources.

Users of advanced technologies play an important role in innovation in many of the industries examined in this volume, especially those in the IT sector. Prox-

[5]"Largely as a result of the lack of federal funding for research, American Universities have become extremely aggressive in their attempts to raise funding from large corporations. . . . Large US based corporations have become so disheartened and disgusted with the situation they are now working with foreign universities, especially the elite institutions in France, Russia and China, which are more than willing to offer extremely favorable intellectual property terms" (testimony before the Subcommittee on Science, Technology, and Space, U.S. Senate Commerce Committee of R. Stanley Williams, September 17, 2002; statement reproduced at http://www.memagazine.org/contents/current/webonly/webex319.html; accessed April 2, 2005).

imity to sophisticated users is an important factor in the decisions of U.S. firms to locate a portion of their innovation-related activities offshore. An important part of the R&D infrastructure that attracts (or retains) investment in innovation-related activities supports user-driven applications in advanced technologies. One of the most celebrated recent examples of investment in such infrastructure was the public investment in the computer-networking infrastructure (originally referred to as ARPANET) that laid the foundations for the Internet. U.S. policy supported public and private investments in the networking technology and infrastructure, and U.S. trade policy encouraged widespread imports and adoption by users of low-cost desktop computing hardware. These policies helped create a large domestic "testbed" for demanding users of computing technology to develop new applications, which in turn helped propel the explosive growth during the 1990s of commercial investment in Internet-related firms (Mowery and Simcoe, 2002).

One contemporary (and closely related) equivalent to the computer-networking infrastructure of the ARPANET and NSFNET is broadband communications technology, which remains less widely available in the United States than in other (notably Nordic) nations (Turner, 2006). Moreover, differences in such access between urban and rural users depress the size of the domestic market for advanced applications developed on this testbed by innovative users. Broadband access is an indispensable foundation for continued growth in the user-driven innovation that now is prominent in many of these industries. In this area, as well as others affecting the viability of user-led innovation, public policy and private investment should support the development of widely accessible testbeds for sophisticated users to develop new applications and business models. Such an infrastructure could support the development of new firms and industries from domestic sources, investments in related fields from foreign firms, and continued innovation and growth in the U.S. economy.

The broader process of economic globalization, of which the restructuring of innovation-related activities is one part, is on the whole beneficial for the United States. Consumers benefit from higher-quality, lower-cost, and more innovative products; employees benefit from the ability to exploit their skills in a global rather than a domestic market; firms benefit from lower costs and economies of specialization through vertical specialization and increased collaboration; and the processes of trade liberalization can have beneficial political consequences for international relations as well. In addition, of course, literally millions of non-U.S. citizens benefit from the expanded economic opportunities in their home nations provided by the process of economic globalization.

Nevertheless, the distributional consequences of trade liberalization and globalization are significant, and, in a democracy, the political effects of worker displacement and flat or declining wages can intensify resistance to trade liberalization. These concerns are affected much more by relocation of manufacturing and services employment, rather than by change in the structure of innovation-related activities, and raise issues that go far beyond the focus of the studies in this volume. Nevertheless, in the absence of more effective policies within the United States to address the legitimate concerns and needs of the domestic economic "losers" from globalization, political resistance to policies seeking to further liberalize international flows of trade and investment seems likely to grow. And such political resistance has the potential to undercut the globalization in innovation-related activities that has proven highly beneficial to U.S. and non-U.S. citizens alike.

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