United States Government Accountability Office

GAO

Report to Congressional Committees

September 2006

OFFSHORING

U.S. Semiconductor and Software Industries Increasingly Produce in China and India

Accountability ★ Integrity ★ Reliability

GAO-06-423

GAO
Accountability · Integrity · Reliability
Highlights

Highlights of GAO-06-423, a report to congressional committees

September 2006

OFFSHORING

U.S. Semiconductor and Software Industries Increasingly Produce in China and India

Why GAO Did This Study

Much attention has focused on offshoring of information technology (IT) services overseas. "Offshoring" of services generally refers to an organization's purchase from other countries of services such as software programming that it previously produced or purchased domestically. IT manufacturing, notably semiconductor manufacturing, has a longer history of offshoring of manufacturing operations. Under the Comptroller General's authority to conduct evaluations on his own initiative, GAO addressed the following questions: (1) How has offshoring in semiconductor manufacturing and software services developed over time? (2)What factors enabled the expansion of offshoring in these industries? (3) As these industries have become more global, what have been the trends in their U.S.-based activities?

What GAO Recommends

GAO makes no recommendations in this report.

GAO provided copies of our draft report to the Departments of State and Commerce. The Department of State did not provide comments; the Department of Commerce agreed with our findings.

www.gao.gov/cgi-bin/getrpt?GAO-06-423.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Loren Yager at (202) 512-4128 or yagerl@gao.gov.

What GAO Found

The U.S. semiconductor industry began offshoring labor-intensive manufacturing operations in the 1960s, followed in the 1970s and 1980s by increasingly complex operations, including wafer fabrication and some research and development (R&D) and design work. Semiconductor assembly and testing was the first to move to Asia, followed by fabrication and, more recently, by some design operations. Software services offshoring began in the 1990s after Internet communications made it possible to trade services such as software programming and software design. The year 2000 changeover hastened this offshoring trend related to software services because programmers knowledgeable in the appropriate programming languages were available, primarily in India. In the 2000s, firms further expanded their offshoring operations, based on the low-cost and high-quality work from the offshored services undertaken in the late 1990s.

Although a lower labor cost was initially a key factor that attracted firms to offshore locations, other factors such as technological advances, available skilled workers, and foreign government policy, also played roles. Technological advances helped firms in the semiconductor industry improve their management of global supply chains and logistics. Regarding software services, technological advances opened the way to trade in programming and other software services. Foreign government policies in Taiwan and China created favorable investment conditions for U.S. semiconductor firms. India changed its emphasis from state-owned enterprises in the 1970s to an environment more amenable to private enterprise by the mid-1980s. Although its restrictions on foreign investment constrained the software services industry's overall development, India established software technology parks in 1990 to give domestic firms preferential access to the infrastructure essential for offshored operations.

Although offshoring continues to grow in both the semiconductor manufacturing and software services industries, the United States remains one of the largest and most advanced producers of semiconductors and software services. U.S. production data show that both industries have largely rebounded from the 2001 recession. Employment data show a mixed picture, with semiconductor employment remaining flat and software employment mostly recovering. The United States has global trade surpluses in the semiconductors and software services sectors, although production is increasingly shifting to Asia. Both U.S. industries have become global, sourcing components from many locations overseas. U.S. firms have offshored increasingly complex products, essentially moving up the value chain. The ability of the United States to compete depends on research and development investment, innovative academic environments attracting top-quality students, and a competitive business environment. It will be important for U.S. businesses and policymakers to keep alert to technological changes and competitor countries' strategies while enhancing the elements of the innovation environment in the United States.

Contents

Figures

Abbreviations

ACM	Association of Computing Machinery
ATP	Advanced Technology Products
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
CMM	Capability Maturity Model
CMMI	Capability Maturity Model-Integration
EU-25	European Union
FDI	foreign direct investment
ICT	Information and Communications Technology
IDM	Integrated Device Manufacturer
IT	information technology
MOFA	majority-owned foreign affiliates
MNC	multinational company
NAICS	North American Industry Classification System
PPP	purchasing power parity
R&D	research and development
SIA	Semiconductor Industry Association
SIC	Standard Industrial Classification

United States Government Accountability Office
Washington, D.C. 20548

September 7, 2006

Congressional Committees

Foreign competition over the last several decades has contributed to a decline in U.S. manufacturing employment, while U.S. firms have also moved some production activities to foreign locations in order to reduce costs or gain access to foreign markets. Concerns about U.S. manufacturing job losses have been allayed somewhat by the prospect of large numbers of high paying jobs developing in U.S. knowledge-based services industries, such as in the information technology (IT) sector. However, some types of knowledge-based services have become more easily tradable within the past 10 years due to the spread of the Internet, and concerns have now also arisen about what the offshoring of these types of activities may mean for the United States.

In response to widespread congressional interest, we have undertaken a body of work related to offshoring under the Comptroller General's authority to conduct evaluations on his own initiative. In this report, one in a series of reports on services offshoring,[1] we address offshoring trends in two important U.S. information technology industries—semiconductor manufacturing and software services. To analyze the U.S. semiconductor and U.S. software industries' experiences with offshoring, we addressed the following questions:

- How has offshoring in semiconductor manufacturing and software services developed over time?
- What factors enabled the expansion of offshoring in these industries?
- As these industries have become more global, what have been the trends in their U.S.–based activities?

To answer these questions, we analyzed data and other research to develop a broad understanding of these industries. We conducted research on how

[1]GAO, *International Trade: Current Government Data Provide Limited Insight into Offshoring of Services*, GAO-04-932 (Washington, D.C.: Sept. 22, 2004); GAO, *International Trade: U.S. and India Data on Offshoring Show Significant Differences*, GAO-06-116 (Washington, D.C.: Oct. 27, 2005); and GAO, *Offshoring of Services: An Overview of the Issues*, GAO-06-5 (Washington, D.C.: Nov. 28, 2005). See also Related GAO Products at the end of this report.

these industries developed offshoring relationships in specific countries—Taiwan and China for semiconductor manufacturing and India for software services. We examined the available literature on both industries; analyzed U.S. government data on foreign investment and trade in these industries; and interviewed representatives from firms and private sector associations, as well as industry analysts in the United States, Taiwan, China, and India. We conducted our analysis in accordance with generally accepted government auditing standards from October 2005 through August 2006. A detailed description of our methodology appears in appendix I.

Results in Brief

Over the past 40 years, the extent and complexity of semiconductor manufacturing and software services offshoring have grown as U.S. firms sought low-cost, high-quality workers in response to commercial competition. In the 1960s, U.S. firms offshored the labor-intensive stages of semiconductor manufacturing to make use of low-cost, unskilled foreign labor and to gain access to foreign markets. They maintained capital-intensive, highly-skilled wafer fabrication and design in the United States and offshored assembly operations for products generally destined for the U.S. market. In the 1980s, semiconductor firms moved some wafer fabrication activities to Asian contract manufacturers to reduce financial risk. Taiwan was a key offshore location for U.S. semiconductor manufacturers, initially for assembly and testing and later for fabrication. As China opens its market, Taiwan manufacturers are transferring some operations there, furthering China's role as a rising player in the industry. More recently, U.S. firms have offshored more complex research and design activities; they have also sought to take advantage of Asian engineering talent and to target rapidly growing Asian markets. In the area of software services, firms began to offshore operations in the mid-1990s due to the need for skilled labor and cost reduction. Offshoring of software programming work, in particular, expanded in the late 1990s with the need for additional programmers to prepare for the year 2000 changeover. As telecommunications infrastructure expanded overseas and foreign countries liberalized their economies in the 1990s, firms turned to software programmers in other countries, such as India and Ireland. As firms experienced cost savings and observed high-quality work in these offshore locations, they expanded offshore operations to include more advanced operations, such as software design and systems integration.

Although a lower labor cost was initially a key factor that attracted U.S. companies to many offshore locations, other factors such as technological advances, available human capital, and foreign government incentives were also important to the expansion of offshoring. For firms in the semiconductor industry, technological advances enabled improved management of their global supply chains. For example, sophisticated communication and product tracking technologies made possible efficient international product delivery systems. The development of telecommunications technology initially enabled software services firms to offshore basic software programming services. Such technology changes led firms in each industry to extend their basic business model to include global teams spread across multiple regions of the world and comprising foreign workers with high-quality skills. U.S. firms' offshoring decisions also have been affected by a variety of foreign government policies. Semiconductor firms responded to the Taiwan government's incentives and to China's policies aimed at attracting semiconductor industry investments. Software services firms benefited from the lifting of certain Indian government restrictions and from incentives offered by India. Nevertheless, firms also encounter risk factors in offshoring; among these are geopolitical risks, the quality of infrastructure, and the absence of legal protection for intellectual property rights.

Despite the growing scope and sophistication of offshore activities, the United States continues to be one of the largest and most advanced producers of both semiconductors and software. U.S. companies are leaders in both industries, while foreign companies have established their own operations in the United States to access U.S. technology, skilled labor, and market. Although both semiconductor and software industries faced a downturn during the 2001 recession, U.S. production data show that they have generally rebounded and are growing. Employment data show a mixed story, with semiconductor employment remaining relatively flat and software employment rebounding. Trade data indicate that the United States has global surpluses in both semiconductors and software, although production is increasingly shifting to Asia. More broadly, the United States maintains several strengths that help foster and commercialize innovations in high technology sectors such as semiconductors and software. These include its higher education system, spending on research and development, and a competitive business environment.

In this report, we make some observations comparing the offshoring experiences in semiconductor manufacturing and software services. We note the importance both of understanding the implications of rising foreign competition and technology change and of enhancing traditional

U.S. strengths in areas supporting innovation and new commercial applications.

We received written comments on a draft of our report from the Department of Commerce, which generally agreed with our finding. (See app. IV.)

Background

"Offshoring" generally refers to an organization's replacement of goods and services produced domestically with imports from foreign sources.[2] For example, if a U.S.-based company decides to move its computer programming activities to an overseas supplier, this would be considered offshoring. The overseas supplier may be an affiliate of the company, in which case the company has also invested overseas. In contrast, the supplier may be unrelated to the domestic company, in which case the company has outsourced its computer programming activities, as well as offshored them.

Semiconductors are devices that enable computers and other products such as telecommunication systems to store and process information. Semiconductor device fabrication is the process used to create "chips," the integrated circuits that are present in everyday electrical and electronic products. It is a multiple-step sequence of photographic and chemical processing steps during which electronic circuits are gradually created on a wafer made of pure semiconducting material, most commonly silicon. Improvement in the performance of increasingly sophisticated electronics products depends on more powerful semiconductors that can store more information and process it faster. Demand for semiconductors is driven by the demand for computers and communications products that use them.

The semiconductor manufacturing process can be divided into three distinct stages: (1) design of the semiconductor integrated circuit, (2) fabrication of the semiconductor wafer, and (3) assembly and testing of the finished integrated circuit. The design and fabrication processes are the most capital-intensive, while the assembly and testing process tends to be more labor-intensive, although still relatively technologically sophisticated. For example, semiconductors are designed by computer engineers with the

[2]For a discussion of definitions of offshoring and outsourcing, see GAO, *International Trade: Current Government Data Provide Limited Insight into Offshoring of Services*, GAO-04-932 (Washington, D.C.: Sept. 22, 2004), p. 55.

assistance of advanced software. They are then fabricated using chemicals, gases, and materials combined in an intricate series of operations using complex manufacturing equipment to produce wafers containing a large number of chips. During assembly, the chips are assembled into the finished semiconductor components and tested for defects. The finished semiconductor consists of millions of transistors and other microscopic components.

The technological complexity of semiconductors is indicated by the diameter of the wafer and the density of the etched lines (feature size) on the wafer. The size of the wafer is an important element because the number of chips per wafer increases dramatically as the wafer size increases. The current leading-edge manufacturers produce 12-inch (300 millimeters) wafers.[3] Smaller feature size measured in microns allows for more components to be integrated on a single semiconductor, thus creating more powerful semiconductors. Each reduction in feature size—from 0.35 micron to 0.25 micron, for example—is considered a move to greater technological sophistication.

The software services industry also includes several types of services and levels of technological sophistication. Software services include writing individual software programs or combined "modules;" supporting these programs and modules once they are installed on computers; designing software networks, which might include various software programs, as well as systems of networks; integrating and maintaining these networks and systems as they are applied to clients' tasks; and managing and operating clients' overall computer systems.

Software services are now broadly diffused throughout the U.S. economy. Firms across most industries now use some form of software services—whether it is basic accounting software, inventory control software, or a much more complex software product applied to manufacturing operations. Automobile companies, for example, use advanced computer software in the design of new car models, on production lines that manufacture these cars, and in the cars themselves that now contain electronic components.

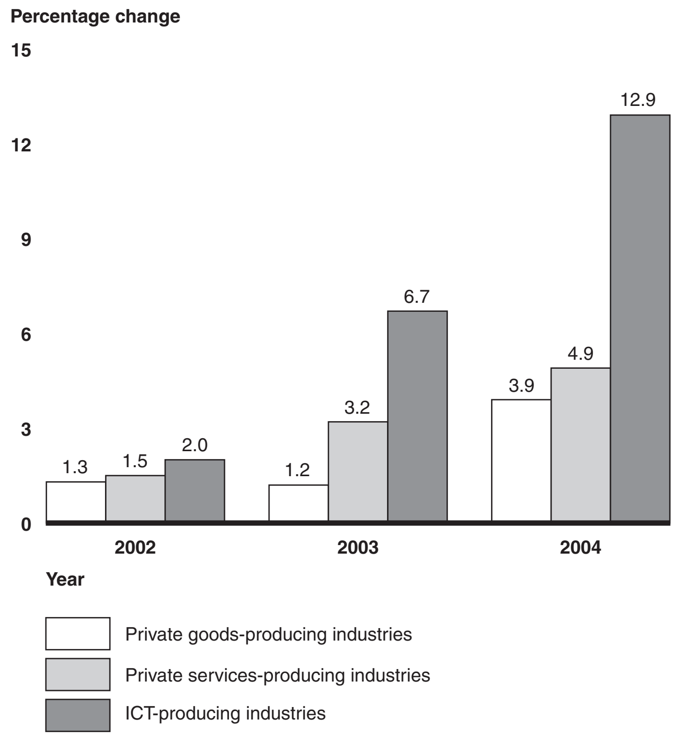
[3]Moving from an 8-inch (or 200 millimeter) wafer to a 12-inch (or 300 millimeter) wafer increases the number of semiconductor chips by 2.25 times.

Software services generally range in complexity from routine software programming and testing to complex software programming, software project management, and higher-end software systems integration, architecture, and research. In general, software programs and modules can be produced in various locations; integrating these requires some focal points capable of working closely with the various locations.

Both semiconductor manufacturing and software services are key industries within the broader information and communications technology (ICT) sector; they have contributed significantly to overall U.S. growth and productivity. For example, semiconductor and related device manufacturing in the United States represents about 24 percent of the total value of the ICT sector's computer and electronic products manufacturing. Software services comprise about 48 percent of the total production of the categories of services industries included in the broader ICT sector—publishing industries (includes software), information and data processing services, and computer systems design and related services (averaged over 1990 to 2004).

Although the ICT sector represents a small share of the overall U.S. economy (about 4 percent), it has contributed significantly to U.S. economic expansion. According to the Department of Commerce's Bureau of Economic Analysis (BEA), the ICT sector accounted for about 11 percent of total economywide value-added growth in 2004. Examining value-added growth is a useful way to compare growth rates across industries because it measures only the increase in output due to that industry, excluding any inputs or materials from other industries. Therefore, value-added growth measures the changes in output due to increases in factors such as labor and capital and to improvements in the productivity of those factors. Figure 1 shows that, from 2002 to 2004, the ICT sector's growth in real value added accelerated more than any other industry group. Although the ICT sector's growth slowed in 2001 during the recession, annual real growth has recently accelerated from 2.0 percent in 2002, to 6.7 percent in 2003, and to 12.9 percent in 2004.

Figure 1: Annual Growth in Real Value-Added by Industry Group, 2002–2004



Source: BEA.

The ICT sector also contributes to productivity in the rest of the economy. For example, other manufacturing and services sectors, such as automobiles and banking, have become more productive as they have used the latest products and advances from the ICT sector. Economic research has generally found that the investments made in ICT sector products by other industries contributed to a rapid economywide increase in productivity during the 1990s.[4] In addition, the technological advances and competition within the sector have resulted in declining prices and rising performance in ICT products. This, in turn, has contributed to lower rates

[4]For example, see Dale Jorgenson "Information Technology and the U.S. Economy" *American Economic Review*, March 2001, 91(1), pp.1-32, and Kevin Stiroh "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?" *American Economic Review*, December 2002, 92(5), pp.1,559-1,576.

of inflation throughout the economy as other sectors benefit from these improvements.

We present information on multinational companies' global operations in semiconductor and software services in appendix II.

U.S. Firms Continue to Offshore Increasingly Complex Semiconductor Manufacturing Activities and Software Services

The U.S. semiconductor industry has foreign operations in several locations, notably in Taiwan and China. The U.S. software services industry has turned to India for a significant share of its offshoring operations. The types of semiconductor manufacturing and software services that U.S. firms have offshored to Taiwan, China, and India have become more complex over time. U.S. semiconductor firms first offshored labor-intensive assembly operations in the 1960s, then wafer fabrication, and more recently, higher value-added activities, such as advanced fabrication and design. The offshoring of software services largely began in the 1990s in preparation for the year 2000 transition. Much like semiconductor products, the types of software services that firms have offshored have become progressively more complex as firms expanded their offshore operations to customized applications requiring highly skilled workers.

Semiconductor Manufacturing Moved Offshore as Competition from Other Countries Developed; Firms Offshored More Complex Production Over Time

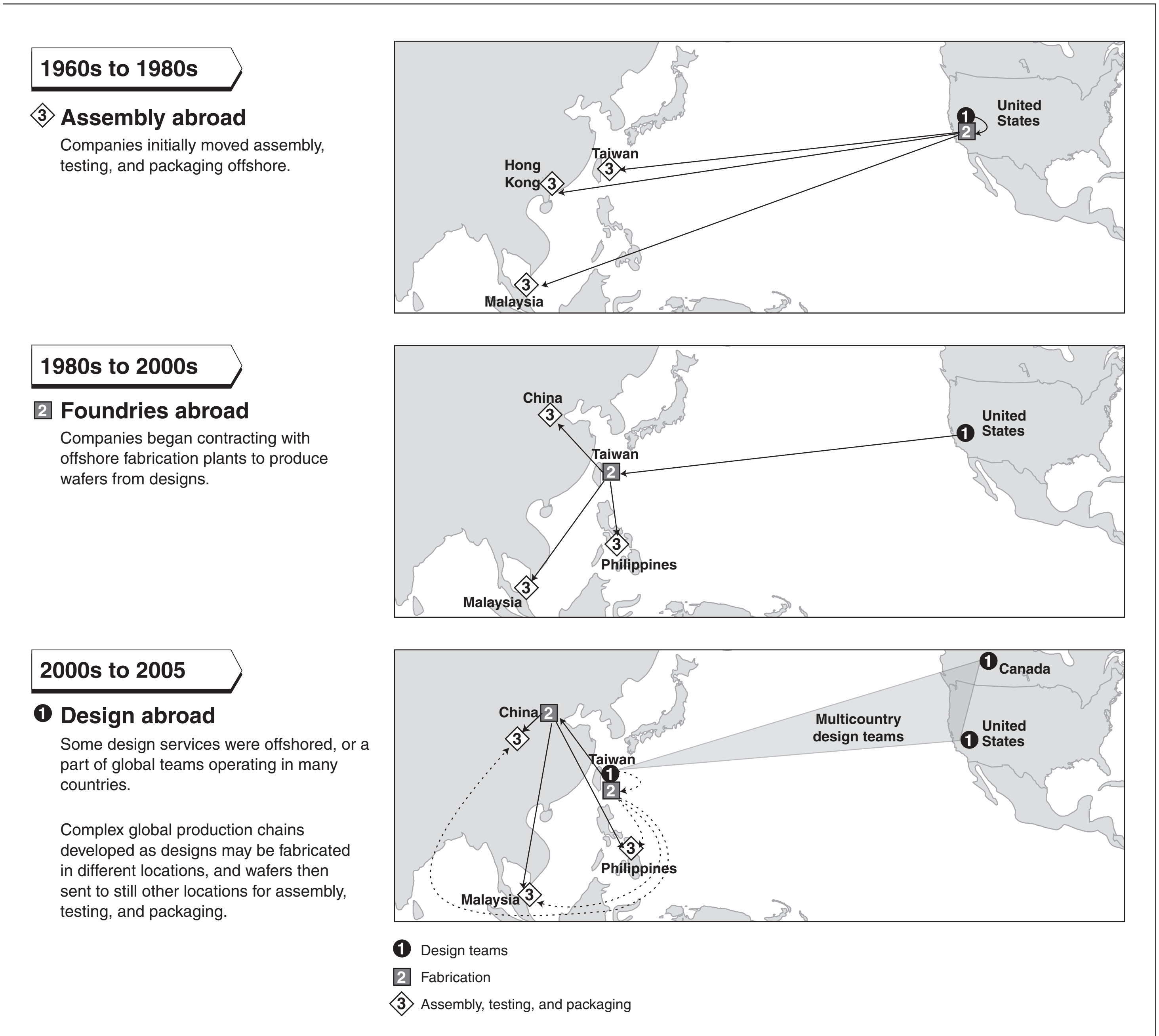
Offshoring in semiconductor manufacturing began in the 1960s with labor-intensive manufacturing activities, such as assembly. U.S. firms invested in overseas manufacturing facilities to perform the labor-intensive assembly of semiconductors for export to the United States. Firms domestically sourced the design and fabrication of higher-skilled, more capital-intensive semiconductor manufacturing activities and then shipped the semiconductors to Asia for assembly. The finished semiconductors were returned to the United States for final testing and shipment to the customer. According to some industry experts, offshoring of assembly work kept the U.S. semiconductor industry cost-competitive as new foreign rivals emerged in countries such as Japan.

The overall U.S. business models for semiconductor manufacturing changed in the 1980s. Two types of company models developed for semiconductor production. Some companies, known as Integrated Device Manufacturers (IDMs), conduct their own research, produce their own designs, and operate their own fabrication plants to produce semiconductor wafers.[5] Other companies, known as fabless design firms, develop their own designs and contract with independent fabrication plants, known as foundries, to produce their wafers. Foundries emerged during the 1980s as firms in Asia, particularly Taiwan, began to specialize in wafer fabrication. With the emergence of overseas foundries, U.S. firms developed global supply chains for sourcing different parts of the semiconductor production process over multiple global locations. They continued to design in the United States and other developed countries, while contracting with foundries in Taiwan to perform capital-intensive wafer fabrication. They also continued domestic fabrication, but Asian countries increased their share of overall production—with Taiwan expanding as a major supplier of fabrication services and China emerging as a new source of fabrication services in the late 1990s.

In recent years, some U.S. firms have offshored increasingly complex semiconductor fabrication and design activities—essentially going up the value chain (see fig. 2). As firms in other countries, notably Taiwan, became more adept at producing more complex semiconductors, U.S. firms increasingly turned to offshore manufacturers to produce these semiconductors. The most complex semiconductors now manufactured in fabrication plants (commonly called fabs) are 12-inch (300 millimeter) wafers with submicron feature size. U.S. firms were leaders in developing 12-inch wafers. According to industry experts, firms have offshored design services to Taiwan due, in part, to maintain close contact with Asian customers to meet their specific requirements. Also, as semiconductor manufacturing becomes more complex, some experts have noted, it becomes all the more important to develop close relationships among design and manufacturing activities, so as to enable feedback discussions.

[5] However, IDMs may also use foundries in addition to their own fabrication plants to handle excess demand or certain production runs that are not economical for the IDM to produce.

Figure 2: Semiconductor Manufacturing Trends, 1960–2005



Sources: GAO (data); MapArt (map).

The gap in semiconductor manufacturing capabilities has narrowed between the United States and Taiwan and China. Currently, Taiwanese and Chinese foundries are capable of producing technologically sophisticated semiconductors. For example, Taiwanese foundries are now capable of producing integrated circuits as small as 0.09 microns, and some Taiwanese firms provide design services to support this level of semiconductor technology. In addition, according to industry experts, the newest semiconductor manufacturing facilities in China are capable of producing integrated circuits up to 0.13 microns in size, with one Chinese foundry known to be producing circuits at the 0.09 micron size. Thus, currently the most advanced manufacturing facilities in Taiwan and China manufacture integrated circuits that are only one generation or less behind state of the art.

U.S. Firms Offshored Software Services in the Mid-1990s and Increasingly Offshore More Complex Activities

The software services industry was one of the first services industries to offshore significant activities as U.S. firms recruited foreign software programmers, particularly in India. Before the widespread use of the Internet, it was not economical to export software. U.S. firms either invested in overseas affiliates in India to directly provide software services for the firm or hired Indian programmers to work temporarily on-site at firms' U.S. locations. Beginning in the 1990s, Internet communications combined with the availability of satellite connections and reduced telecommunication costs made it possible for foreign software programmers to remain abroad while working for U.S. clients. Many types of U.S. firms began re-engineering their business processes to concentrate on core competencies and outsource or offshore other activities, such as writing software programs. The offshored activities were those that could be reduced to step-by-step instructions, digitized, and performed at a distance.

In the late 1990s, preparations for the year 2000 changeover contributed to U.S. firms' further use of foreign software programmers who were knowledgeable in certain programming languages. U.S. firms turned not only to foreign software programmers who were temporarily employed in the United States but also to programmers overseas, particularly in India, who provided work directly to U.S. clients. In recent years, U.S. firms have offshored increasingly complex software services, going up the value chain as occurred in the semiconductor industry. Examples of less sophisticated software services are operations involving basic computer language coding or programming and managing computer databases. More complex offshored services include advanced software design and development activities and researching, designing, developing, and testing new software technology.

U.S. firms experienced high-quality work in offshore locations; for example, they discovered that firms in India have the capabilities to produce high-end software services, such as software design at a low cost. In addition, firms often combine highly skilled labor available in India with skilled labor in other countries to create global teams with specific skill sets. For example, one firm in India stated that a firm might begin a high-end software development project in India and then transfer the work to a team in Ireland for further development before delivery to a U.S. client. Firms also use global teams to better serve local markets worldwide by providing customized programming services to local clients.

Currently, the types of offshored software services activities now include advanced software engineering and research and development. For example, in recent years Indian and multinational firms, including U.S. affiliates, have established high-technology research and design facilities in India to perform such high-end software services as software engineering and software product development. According to software services industry experts in India, many of these facilities employ hundreds of software engineers to develop and test a wide range of new high-end software designs and products for export to global customers. Some firms in India stated that the quality of high-end software design and development activities in India, combined with firms' need to introduce new products and new technologies, have attracted increasing interest in offshoring software development to India. Nevertheless, the bulk of offshored software services in India can be characterized as lower-level work, mostly in the applications development segment of the industry. Applications development primarily requires programming skills and has limited face-to-face interaction. Moreover, applications development can easily be segmented and standardized, features that characterize offshoring software services.

Technological Advances, Availability of Talented Human Capital, and Foreign Government Policies Contributed to Increased Offshoring of Semiconductor Manufacturing and Software Services

The combination of technological advances, available human capital, and foreign government policies has created a favorable environment for offshoring. Many firms in semiconductor manufacturing and software services use offshoring in their business models to increase their global competitiveness by lowering costs and gaining access to foreign markets. Advances in telecommunications enabled semiconductor firms to improve their logistics and inventory controls; they also were particularly important to the offshoring of software services. Firms in both sectors initially sought low-cost labor, but they expanded the scope of their offshoring activities as they discovered and helped develop highly educated workforces in Taiwan, China, and India. Foreign government policies played different roles in the countries we visited. In Taiwan and China, the national governments pursued various industrial policies to promote semiconductor manufacturing and, in India, the loosening of regulations and the availability of government-supported software technology parks afforded the software industry opportunities to grow relatively unregulated. Although offshoring conveys benefits to firms that choose to locate operations overseas, it also encompasses business risks that challenge management skill. See table 1 for an overview of the factors that have contributed to increased offshoring.

Table 1: Many Factors Contributed to a Favorable Environment for Offshoring in Semiconductors and Software Services

Factors	Semiconductors (Taiwan, China)	Software (India)
Technology		
Computer-related infrastructure	Inventory control, radio frequency identification of products, logistics improvement	Telecommunications and broadband capacity improvements
Physical infrastructure	Roads, ports, trucking improvements	Fiber optics
Human capital		
Workers	Assembly workers with less education; research and development and design professionals with higher education	Well-educated IT workers
English language ability	English not required	English essential
Cost of human capital	Wage rates lower than U.S. wage rates; labor costs represent a small share of fabrication plants.	Wage rates lower than U.S. wage rates; demand is causing wages to increase.
Government policies		
Education/training	Vocational training emphasized	Government promoted college education as a cultural value.

(Continued From Previous Page)

Factors	Semiconductors (Taiwan, China)	Software (India)
Investment incentives	Various incentives available in science parks; government shares risk; China used a preferential value-added tax incentive to attract investment in the early 2000s.	Software technology parks include income tax credits, duty-free entry of capital goods, and access to high-speed telecommunications.
Favorable tax/ land policies	Offered by regional governments	Less prevalent generally, but favorable leasing terms are available in science parks.
Private sector regulation	Highly regulated, licensing required	Software less regulated than some other private industry; private entrepreneurship is the prevailing model.

Source: GAO.

Technology Launched Important Changes in Semiconductors Manufacturing and Software Services

Improvements in telecommunication technology helped to expand the degree of offshoring in both semiconductor manufacturing and software services. With improved communications, U.S. semiconductor firms were able to create tighter linkages with overseas suppliers, and software services firms developed global teams that could transfer digitized information over the Internet.

Technology Improvements Allowed Semiconductor Firms to Develop More Efficient Global Supply Chains

Semiconductor manufacturing firms improved their management of supply chains through better telecommunications, logistics management, and modern transportation. Telecommunications has allowed better monitoring of the movement of products. For example, foundries in Taiwan use Internet-enabled software that allows real-time communication between engineering teams in different locations. Some U.S. companies use radio-frequency identification tags in Taiwan and China to track products shipped from these manufacturing locations to distribution centers in other countries. According to a representative of one U.S. firm, this technology has reduced the need for inventory sourcing redundancy, thus reducing inventory cost and the associated employment costs.

Logistics management is an important part of global business. Taiwan's competitive logistics industry has offered advanced computerized systems that assist in the management of purchasing, storage, delivery, and distribution of products. According to a Taiwan government official, Taiwanese companies can provide production orders to their clients in 2 days. According to an industry researcher, the automation of the semiconductor assembly process also has improved efficiency in the overall semiconductor infrastructure, such as packaging facilities.

Modern transportation options using more powerful computer systems, advanced software, and telecommunications make faster delivery possible. Countries are upgrading all elements of their transportation infrastructure—airports, seaports, modern roads, and trucking. Because a product may travel around the world more than once during the production process, efficient transportation systems are essential. For example, China has made numerous improvements to its transportation infrastructure to permit more efficient distribution. According to one Internet firm operating in China, the transportation infrastructure within China for delivering the physical products to customers—an essential component for online auction sites—did not exist before the year 2000. China reportedly invested $30 billion in 2004 alone to improve its network of roadways.

The Software Services Industry Changed Its Global Business Model

In the software services sector, telecommunications improvements have changed the types of software services traded, the way the work is done, and the telecommunications investments made.

First, the essential advance in IT—the introduction of Internet communications—made it possible to trade some services that were previously not tradable. For example, software programs written in standardized programming languages could be digitized and transferred worldwide over the Internet.

Second, global teams have become common elements of firms' business strategies. The ability to transmit data electronically made it possible to specify an application in one firm and develop it in another. Because of the availability of the Internet, teams can work 7 days a week, 24 hours per day to meet customer needs worldwide. These teams' operations could be set up relatively quickly with office space, utilities, and communication tools, such as personal computers with broadband access. The ease of undertaking this type of offshoring has led to an escalating use of offshored IT services, including but not limited to software programming. According to one research firm, the value of IT offshoring and business process offshoring totaled $34 billion in 2005 and could double by 2007.

Finally, the services offshoring model has required investments in global telecommunications infrastructure, such as wired landline and satellite communication services. India has made the investments to facilitate the telecommunications industry. According to the government of India, in

2005, 47 million landline connections and 65 million satellite connections existed in India. Moreover, in 2004, after the telecommunication sectors declined due to overcapacity, one major Indian telecommunications services firm, partly owned by the government of India, purchased a large, privately owned U.S. undersea fiber-optic network linking Asia, Europe, and North America after receiving national security approval from the U.S. government. This acquisition strengthened India's control of low-cost telecommunications infrastructure. According to an Indian government official and several U.S. companies operating in India, the growth in telecommunications infrastructure has also enabled firms to move from India's major cities to smaller, lower-cost surrounding cities.

The Availability of Human Capital Was Key to the Expansion of Offshoring in Both Semiconductor Manufacturing and Software Services

The availability of high-quality workers overseas has been an essential component of the increased use of offshoring for firms in the semiconductor manufacturing and software services sectors. Through experience and training, the talent pool in several countries demonstrated their value to firms seeking skilled workers to perform tasks with various degrees of complexity.

Some Semiconductor Firms Turned to Low-Level Skilled Foreign Workers Initially but Gradually Offshored More Complex Work to Higher-Skilled Labor Forces Overseas

Access to human capital played an important role in the relocation of semiconductor manufacturing firms to Taiwan and China, especially as the need for skilled labor arose, and a quality workforce emerged in these countries. During the earlier phase of semiconductor offshoring in Taiwan, workers did not need advanced training. Taiwan emphasized vocational training during this period. Industry experts stated that, although lower-cost labor was initially attractive for assembly, the labor costs component in semiconductor manufacturing is not a decisive factor for companies' location decisions overseas.[6] New technology has computerized the entire production process, leading to a reduced need for labor and an increased need for skilled workers and managers. According to the representative of one research firm, the quality of the Chinese and Taiwanese workforce makes it easy to train and retain workers in semiconductor assembly and manufacturing.

[6]Semiconductor manufacturing plants cost about $3 billion, with labor costs contributing between 5 and 10 percent.

Taiwan, China, and India are each able to provide a quality workforce, with a plentiful supply of engineers including emigrants who have returned to work in their home countries. Highly trained professionals with experience in U.S. firms assisted the development in each of these three countries of their semiconductor and software industries. According to one research firm, more than 5,000 overseas students and professionals return to China each year, bringing with them Western knowledge and skills.[7] For example, several firms operating in China told us that Chinese returnees who have studied or worked abroad are an important part of their staffs. India, Taiwan, and China are each graduating IT and other engineers in large numbers. For example, China's potential supply of engineers is large; according to one U.S. study, the number of Chinese engineering graduates with bachelor's degrees in 2004 numbered 351,537, as compared with 137,437 in the United States.[8] Moreover, engineers in Taiwan, China, and India typically earn less than their counterparts in the United States. For example, Taiwan's domestic supply of engineers can be hired at approximately half the cost of engineers in the United States.

Software Services Firms Find a Large Supply of Human Capital Overseas with Top Quality Skills

We reported in 2004 that access to human capital, particularly lower-wage skilled labor, an educated workforce, and quality local vendors facilitated software services offshoring. India is the leading example of this trend. For example, Indian wages represent a fraction of the cost of hiring U.S. counterparts, with the salaries for Indian IT engineers starting at $5,000. According to industry experts, the increasing demand for these workers is causing salary rates to increase somewhat. Yet lower wages does not tell the entire story because India also provides a skilled workforce. India's leading software services association reports that 44 percent of India's services professionals possess at least 3 years of work experience. Moreover, many Indian nationals who studied computer technology in the United States and gained experience with U.S. IT firms have begun to

[7] Chung Chen, Andrew and Woetzel, Jonathan R., McKinsey & Co., "Chips Fall Toward Design," (*South China Morning Post*: Mar. 11, 2002).

[8] See "Framing the Engineering Outsourcing Debate: Placing the United States on a Level Playing Field with China and India" (Duke University: December 2005). This study indicates that China reported a total of 644,106 engineering graduates in 2004, but that data included those with education and training that differ from that attained in U.S. engineering degree programs. We report these data, which are based on a comparison of equivalent engineering programs. For information on U.S. higher education programs related to science and technology, also see GAO, *Higher Education: Federal Science, Technology, Engineering, and Mathematics Programs and Related Trends*, GAO-06-114 (Washington, D.C.: Oct. 12, 2005).

return to India to pursue career opportunities in their native country. Some of these individuals have gone on to create or lead successful firms in India.

India has a strong national emphasis on advanced technical education, and its scientific and educational institutions produce well-trained scientists and engineers. The highly competitive Indian Institutes of Technology trains the upper echelon of talented students and, according to one industry researcher, produces highly skilled engineers with capabilities that match or exceed U.S. talent. In addition, an industry researcher in India stated that nontechnical programs are beginning to offer computer science and software programming courses to prepare students to meet the market demand of the software services sector. According to India's software services association, of the 215,000 engineering graduates in 2003 to 2004, 141,000 specialized in IT (e.g., computer science, electronics, and telecommunications).[9] India's use of the English language gives it a further advantage, making India a prime destination for services offshoring.

Finally, the quality of the firms in India is another factor that is considered when firms decide to offshore services. The quality of local vendors, many with Capability Maturity Model (CMM) certifications, provides a sense of security to firms seeking to offshore software services to India.[10] According to a business association in India, Indian companies work to attain these certifications to demonstrate the high quality of their work. For example, a business representative told us that more than 50 percent of the companies that have CMM Level 5 certifications are located in India. With the update of the CMM to the Capability Maturity Model-Integration (CMMI), the Software Engineering Institute reports 93 Indian and 74 U.S. entities (41 percent and 32 percent, respectively, of the world total) with CMMI certifications as of March 2006.

[9]NASSCOM, *Strategic Review 2005: The IT Industry in India* (New Delhi: 2005).

[10]CMM was established in 1984 through Carnegie Mellon's Software Engineering Institute. The CMM is a framework that describes the key elements of an effective software process. The model was updated to the CMMI in 2000. The CMMI provides companies with guidance for improving their processes and managing the development, acquisition, and maintenance of products and services.

Foreign Government Policies Have Made Foreign Investment Attractive for Semiconductor Firms and Left the Software Services Industry Relatively Unregulated

Foreign government policies contributed to the development of dynamic semiconductor and software services sectors with opportunities for U.S. firms to offshore. The governments of Taiwan and China developed a broad range of policies to promote their respective indigenous semiconductor industries and to attract investment, technology and talent from abroad. India, in its transition from a socialist government to a market-based economy, has liberalized its software services market, thus permitting U.S. firms to access India's low-cost high-quality workforce.

Government Policies in Taiwan and China Have Assisted Their Respective Semiconductor Industries

Taiwan has long pursued industrial policy to encourage the domestic development of science and technology. In 1972, it established a national research institute and within that organization an office to develop its semiconductor industry. Drawing upon the expertise of a U.S. advisory group, Taiwan successfully duplicated elements of the Silicon Valley technology cluster by establishing science-based industrial parks that brought together major universities, research labs, and a dynamic venture capital industry. Its universities feature programs sponsoring research specific to semiconductors, and the government targeted financial and tax incentives to the semiconductor industry. The government also emphasizes vocational training to develop quality resources. As a result, the government of Taiwan helped position its semiconductor industry as an effective contract supplier integral to the U.S. semiconductor supply chain. Its industrial strategy, which has been characterized as "close followership,"[11] integrated Taiwan's industry operations with those of U.S. companies. Although this strategy means that Taiwan's industry may be a step behind the U.S. industry, firms in Taiwan capture high-technology industrial and research functions. As a result of its efforts, Taiwan is now a leading semiconductor producer with top-level manufacturing expertise.

Taiwan's support of a strong semiconductor sector continues to evolve with a project that focuses on integrated circuits manufacturing infrastructure. The government is providing partial financial support to this project, which includes the expansion of university-based training, investments in new technologies, and a design park to focus on system-on-

[11]Howell, Thomas R., testimony to the Committee on Commerce, Subcommittee on Technology, Innovation and Competitiveness, Hearing on Manufacturing Competitiveness, June 8, 2005 (Washington, D.C.). "Close followership" refers to firms that closely align themselves with their customer, adopting technology soon after the customer.

a-chip design.[12] With added pressure from the opening of China's market and the competition from Chinese firms, Taiwan is revisiting its restrictions on the level of technology that firms may transfer to mainland China.[13] In April 2006, Taiwan announced it was removing restriction of the export of low-end semiconductor packaging and testing technology to China.

China's current policies have helped its semiconductor sector to grow dramatically since 2000, but its wafer production represents a relatively small percentage of worldwide production. Nevertheless, China is considered a rising player in the field of advanced technology. Prior to 2004, China's differential value-added tax, since normalized,[14] was a notable policy that led to an influx of semiconductor firms into China —notably from Taiwan—that sought to avoid the impact of the tax. Following Taiwan's strategy, China is creating a modern infrastructure to support semiconductor operations. For example, the government provides tax incentives, preferential loans, and opportunities to locate in special economic zones and science parks. China announced, in 2006, the adoption of a 15-year national technology strategy to develop, among other things, a world-class information sector and to focus on developing independent innovation. The result of China's policies is an expanding semiconductor sector that relies heavily on the expertise of Taiwan's managers and other expatriates whom China is actively recruiting to return to the mainland.[15]

[12]System-on-a-chip design integrates computer components on a single chip. It may contain digital, analog, mixed-signal and radio frequency functions.

[13]Currently, wafer technology using at most .25 micron circuitry may be transferred to the mainland. In February 2006, Taiwan levied a fine of about $155,000 on a leading Taiwanese firm that aided in the establishment of a Chinese chipmaker without Taiwan's approval in violation of its statute governing relationships between people in Taiwan and people on the mainland.

[14]In July 2004, China and the United States resolved the World Trade Organization dispute over China's differential value-added tax, which had disadvantaged U.S. and other foreign firms whose semiconductors were not designed or produced in China. According to experts, China has implemented this agreement.

[15]Taiwan's supplier relationship with the U.S. microelectronics industry is under pressure from the new opportunities for U.S. (and other) firms in China. According to one U.S. legal analysis, Taiwan has placed legal restrictions on the level of technology which its own firms may transfer to mainland China.

India's Software Industry Was Not Subject to Many of India's Restrictive Policies

India's policy for software services differed from the deliberate industrial policy undertaken by Taiwan and China. India's government policy shifted from protection of domestic industries to a gradual liberalization of some regulations. Although India maintains significant controls on some industries, the software services sector was not affected by some of the most restrictive policies, given the small size of its enterprises. Entrepreneurs in the software services sector were able to build the industry based on the special attributes of India —its English-speaking population, its supply of IT professionals, and its favorable telecommunication infrastructure.

Between the 1950s and 1980s, India generally protected domestic firms from foreign competition and undertook a policy of import substitution. India pursued policies that sought to support state-owned enterprises. Where private firms were permitted to operate, a cumbersome licensing bureaucracy controlled their operations. Initially prevented from expanding into higher value-added segments of the industry in the 1980s, software services firms nevertheless found areas of specialization that the government did not restrict. In 1991, India experienced a shortage of foreign exchange, which required liberalization of its economy as a condition to gain support of the International Monetary Fund. This led to further deregulation, which enabled software services to expand. Moreover, in the 1990s, India introduced software technology parks, which are similar to export processing zones. Firms in these parks were given tax exemptions, access to high-speed satellite links, and reliable electric power. India's technical universities trained large numbers of engineers and specialists in their highly selective IT programs. Later reforms of foreign ownership rules, intellectual property protections, and venture capital policy further opened the way for trade in services.

Other Factors Constrain U.S. Firms' Offshoring Decisions

Firms seeking to offshore also encounter risks, including unforeseen costs, geopolitical concerns, cultural differences, infrastructure adequacy, and foreign government requirements. The destination country's legal system and contract enforcement affect firms' decisions to offshore. Both the semiconductor and software services industries have specific concerns about countries' intellectual property protection for their products and make location decisions accordingly. It should also be noted that offshoring places higher demands on firms' internal management skills. Managers must be able to lead teams with cultural differences, establish metrics to assess contract performance, and manage teams located around the world, using telecommunications as a primary tool. Although firms have found some cost savings in labor, nevertheless, they have also found other management challenges that tend to moderate the overall cost savings. One recurrent concern of U.S. firms operating in China is the lack of middle managers with the combination of business training, business acumen, management skill, and creative thinking.

The United States Continues to Be a Global Leader in the Development of Semiconductors and Software at the Most Advanced Levels

While offshore suppliers are playing a larger and more sophisticated role as the industries globalize, the U.S. semiconductor and software industries have remained technological leaders in the most advanced research and development (R&D) and design work, and the United States remains one of the largest producers globally of products in both industries. Available indicators on production, employment, and trade show that both of these industries have generally rebounded since the 2001 recession and continue to grow. Traditionally, the U.S. economy has had several advantages that fostered strong semiconductor and software industries, including its highly competitive university system, talented labor pool, large domestic market for products, high levels of spending on R&D, and competitive business environment.

The U.S. Semiconductor Industry, Rebounding from a Recent Recession, Continues to Be a Global Leader

Despite having offshored some semiconductor operations, the U.S. semiconductor industry remains a global leader in cutting-edge semiconductor chip design and fabrication. U.S. semiconductor production has begun to rise again after a sharp decline during the 2001 recession. However, U.S. semiconductor employment, which also fell during this period, has remained relatively flat since 2003. U.S. exports have also remained flat, but imports declined more sharply creating a U.S. trade surplus in semiconductors. The United States generally exports high-value fabricated chips and wafers to lower-cost locations for assembly and testing. It imports integrated circuits (semiconductor wafers that have been assembled and tested) for use in a variety of industries. However, global demand for finished semiconductors has increasingly shifted to Asia where final assembly of electronic consumer products takes place.

The United States Is a Global Leader in Semiconductor Design and Fabrication

Semiconductor fabrication and design capabilities are spread among traditional producers such as the United States, Japan, the European Union, and newer producers such as South Korea, Taiwan, and China. According to industry experts and data, however, the United States remains one of the largest producers of semiconductors and, in particular, maintains cutting-edge development of both design and fabrication of new semiconductors. Industry estimates of semiconductor capacity vary, but the United States and Japan remain the largest two producers of semiconductors. Although a significant share of new high-end fabrication facilities are being built outside the United States for mass production, the United States is a key location for the fabrication facilities used for development of new semiconductor chips.

As a global industry, U.S. production includes both U.S. companies and affiliates of foreign companies operating in the United States. Foreign companies have established operations in the United States to take advantage of U.S. technology, skilled labor, and the large domestic market, according to industry experts. One estimate suggests that about one-fifth of U.S.-based fabrication capacity was owned by foreign companies in 2001.[16] In addition, foreign companies also take advantage of experienced design teams in the United States. Companies can potentially benefit from having operations in key areas around the globe where innovation is occurring. These operations are able to access the experienced labor pool and new innovations occurring in a particular region and transfer those developments to their global operations. Silicon Valley, California, for instance, is widely known as a key center of innovation in the semiconductor industry.

Similarly, U.S. firms have invested in production capacity in Europe and Asia. However, according to industry experts, U.S. firms have generally not moved their R&D operations offshore. Data on patents and expenditures on R&D also indicate that U.S. semiconductor companies continue to locate their R&D work in the United States. Some industry analysts, though, are concerned that as production increasingly moves offshore to Taiwan and China, it will begin to draw more and more research activities with it.

Industry experts also believe that most U.S. company design work is still conducted in the United States rather than offshore.[17] According to these experts, U.S. companies are significant technology leaders in both the IDM

[16]See Clair Brown and Greg Linden, "Offshoring in the Semiconductor Industry: A Historical Perspective" prepared for the 2005 Brookings Trade Forum on Offshoring of White-Collar Work (May 2005). Estimates are based on work by Robert Leachman and Chien Leachman, of the University of California at Berkeley.

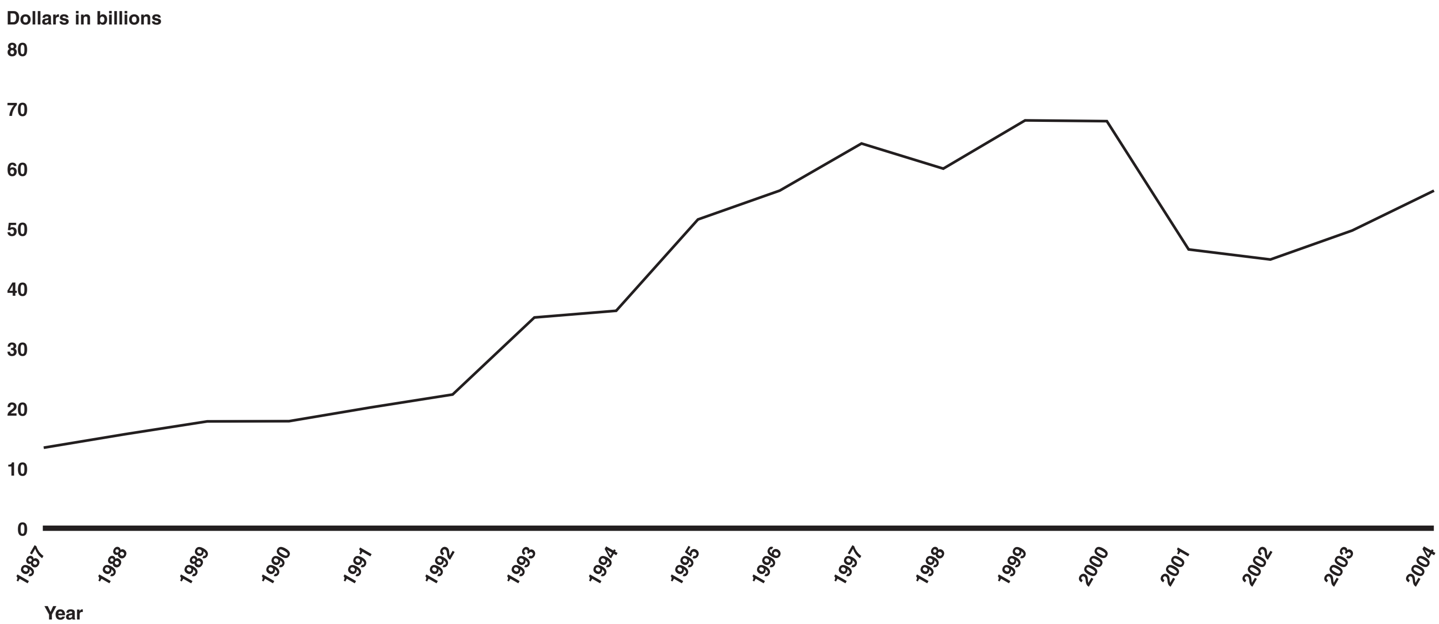
[17]Systematic data on the location of design work, particular leading edge product innovation, is not readily available. Therefore, industry experts rely on the location of companies' offices, patent data, and interviews with company officials to ascertain where design work is being carried out.

and fabless design models. Although U.S. IDMs and fabless design companies operate globally, a larger share of their R&D and design work is conducted in the United States. Most of the fabless design firms are based in the United States, and many of the largest IDM's are also U.S.-based. Also, the development of foundries, particularly in Taiwan, likely allowed a wider range of fabless companies to develop in the United States than may have been possible without the existence of foundries. This is because the high cost of fabrication plants acts as an entry barrier to smaller firms. At the same time, there are a growing number of fabless design firms in Canada, Israel, and Taiwan, and U.S. companies are also operating design offices in these countries. Thus, the global share of design work by fabless companies is becoming less concentrated in the United States.

U.S. Semiconductor Production Rebounding from 2001 Recession, but Employment Has Remained Flat

U.S. production statistics show that the value of semiconductor production in the United States grew steadily during the 1990s even while offshoring expanded. U.S. production of semiconductors and related devices (measured by value-added) peaked in 1999 at about $68 billion, then declined steeply during the 2001 recession. It has since rebounded somewhat to $56 billion in 2004 (see fig. 3).

Figure 3: Value-added Trend for U.S. Semiconductor and Related Device Manufacturing, 1987–2004

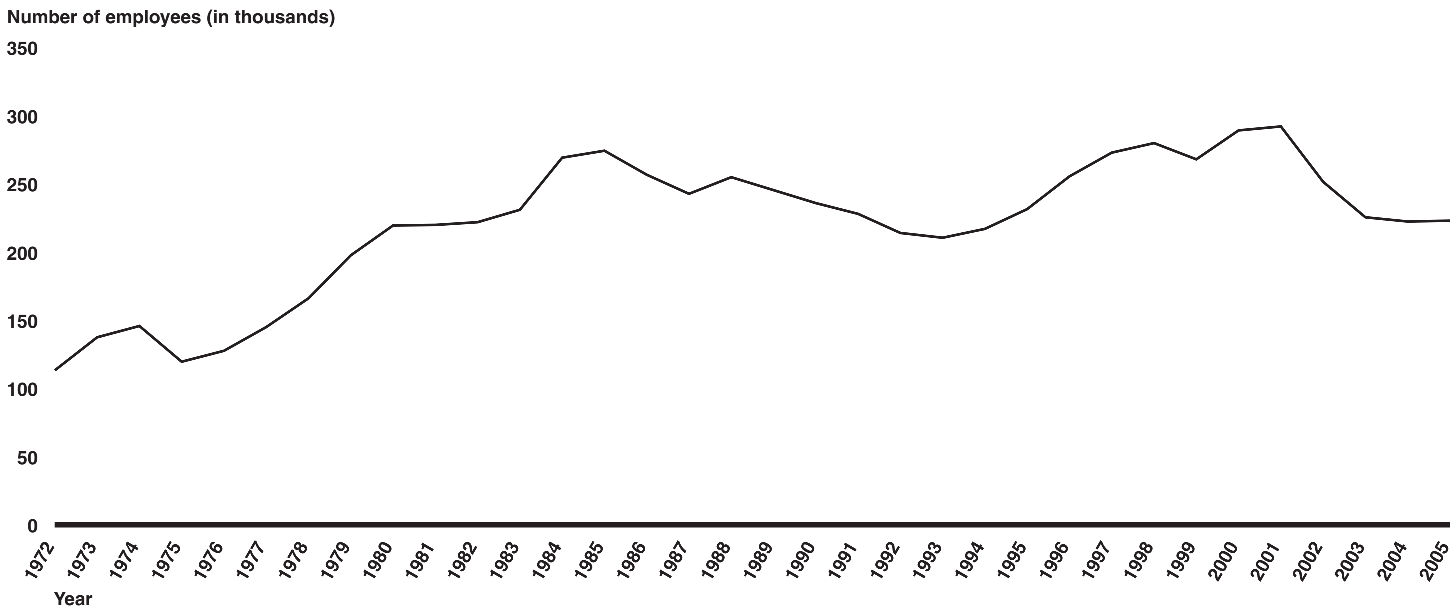


Source: U.S. Census Bureau, Annual Survey of Manufacturers.

Note: This figure shows output of the industry measured by value-added. Value-added measures the dollar value of output in an industry minus the dollar value of intermediate products and raw materials purchased from other industries. For example, semiconductor value-added does not include the value of the raw silicon used in the production of the wafers. The values shown above are in current dollars (unadjusted for inflation). Price indices at this level of industry detail were not available. However, we did examine how the results would change using a higher level industry (computer and electronic products) price index to adjust for inflation (or deflation). Due to declining prices over time in the broader industry, the inflation-adjusted trend was accentuated, such that the rise was much steeper, the decline between 2000 and 2002 was much shallower, and the industry has rebounded. Therefore, we found that our observation that the industry has grown rapidly and has rebounded since the recession is even stronger.

U.S. employment in the semiconductor industry did not rebound after the 2001 recession as production did. After a long decline from the mid-1980s through the early 1990s, U.S. semiconductor employment grew strongly through 2001 (see fig. 4). However, employment dropped sharply from a peak of about 292,000 in 2001 to around 226,000 employees in 2003. After hitting a trough in 2003, employment in the semiconductor industry has been stagnant, although overall U.S. employment across all industries resumed growth in 2004.

Figure 4: Employment Trend for Semiconductors and Related Devices Industry, 1972–2005



Source: Bureau of Labor Statistics.

Employment in the semiconductor industry highlights the broader relationship between productivity growth and job declines in the U.S. manufacturing sector. Figure 5 shows an increase in productivity in the semiconductor and electronic components industry (a broader category than used in fig. 4) over the 15-year period from 1987. The pace of productivity growth sharply increased starting in late 1990s. Industry output continued to grow even after employment declined due to the increase in productivity (output per employee).

Figure 5: Labor Productivity, Employment and Compensation Trends in Semiconductors and Electronic Components Manufacturing, 1988–2004

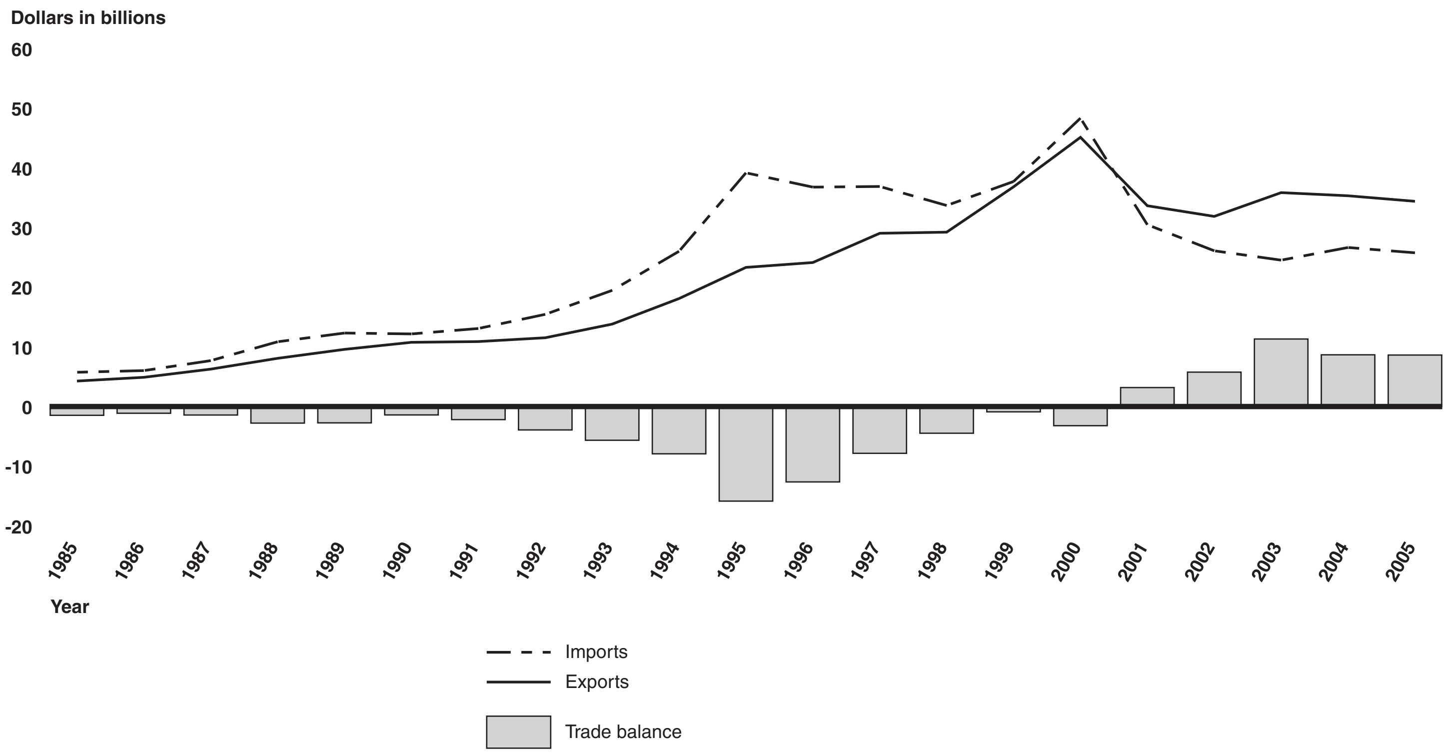
Source: Bureau of Labor Statistics.

Note: Productivity, employment, and compensation are presented here as indexes that represent their values at each year relative to the base year (1997).

The United States Is a Net Exporter of Semiconductors, Particularly High Value-Added Wafers and Chips

Since 2001, the United States has had a trade surplus in semiconductors, exporting more semiconductors and semiconductor components than it imported (see fig. 6). Both imports and exports grew rapidly from 1985 to 1995. From 1995 to 1998, exports continued to grow while imports remained flat. From 1998 to 2000, both imports and exports increased again rapidly, peaking in 2000 at about $48 billion (imports) and $45 billion (exports). From 2001 to 2005, imports declined sharply to about $26 billion, while exports also declined, but then leveled out in 2003 to about $34 billion.

Figure 6: U.S. Imports and Exports of Semiconductors with All Countries, 1985–2005



Source: GAO analysis of U.S. Census Bureau trade statistics.

Note: Trade values are presented in current dollars (unadjusted for inflation). Price indices for making inflation adjustments were not available for the entire time period. However, we did examine inflation-adjusted constant dollar trade values for more recent years, and the findings in our analysis did not change.

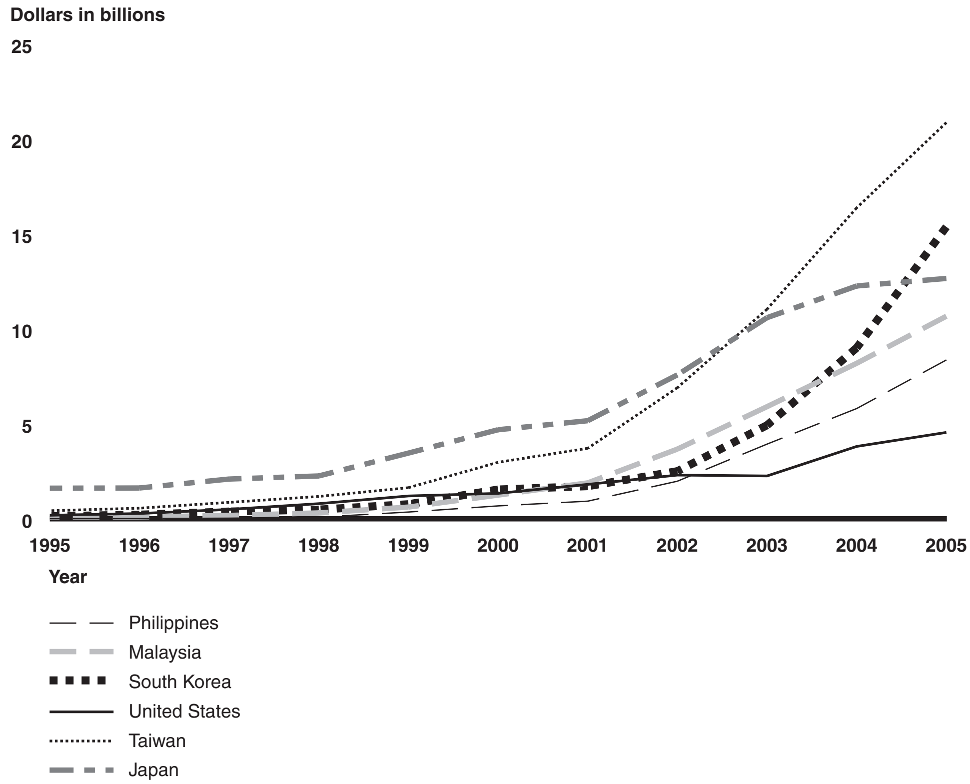
The majority of U.S. *exports* of semiconductors consist of chips and wafers, which are used to produce finished integrated circuits in other countries. The top five destinations for U.S. semiconductor exports were all Asian locations: Malaysia (13 percent), Korea (12 percent), Philippines (11 percent), Taiwan (9 percent), and China (8 percent). Exports of U.S. chips and wafers are the result of the fabrication process, which involves some of the most technologically advanced manufacturing processes.

The majority of U.S. *imports* of semiconductors are finished integrated circuits (such as memory and logic integrated circuits), which are then used in other finished electronic goods, such as computers and cell phones. Finished integrated circuits are the result of chips and wafers being tested, cut, and packaged by separate manufacturing plants usually located abroad. This process, although still technologically sophisticated (and less labor-intensive than in the past), is still significantly less advanced than the fabrication process. In 2005, only 13 percent of imports were chips and wafers whereas 71 percent of U.S. exports comprised chips and wafers.

U.S. Exports to Asia Growing as Demand for Finished Semiconductors Expands in China

The decline in U.S. semiconductor imports since 2000 reflects the movement from the United States to Asia of manufacturing production of electronics products that use integrated circuits. Finished integrated circuits are moving to other countries in Asia, particularly China, for assembly into electronics products, rather than returning to the United States. Therefore, U.S. exports surpassed imports for the first time in 2001. Chinese trade statistics demonstrate the other end of this movement with Chinese imports of integrated circuits soaring over the last 10 years, making China one of the largest markets for integrated circuits in the world. Much of this increase has been supplied by Taiwan, Korea, Malaysia, Japan, the Philippines, and the United States (see fig. 7). Although the United States is sixth in terms of direct exporters to China, some portion of U.S. exports of chips and wafers are passing through other Asian countries for assembly and testing (including China) before use in China's booming electronics industry. As mentioned above, the top destinations for U.S. wafer exports are Malaysia, Korea, Taiwan, the Philippines, and China. Those wafers are assembled and tested before being sent to electronics manufacturers for use in their products. These trade flows show the complex production chains that have developed across multiple countries.

Figure 7: Chinese Imports of Semiconductors by Country, 1995–2005



Source: GAO analysis of Chinese trade statistics provided by Global Trade Information Services.

Note: Trade statistics are presented in current U.S. dollars unadjusted for inflation since an appropriate price index for these imports is not available.

The shift in production and trade flows toward Asia has two consequences. First, because final production increasingly takes place in Asia, the United States imports an increasing share of electronics and telecommunications products (that use semiconductors). Appendix III shows that this is reflected in the growing U.S. trade deficit with Asia and China, in particular, including in advanced technology products. Second, as electronics and telecommunications production chains increasingly locate in Asia, there are benefits to U.S. producers of semiconductors to locate abroad near their customers and take advantage of the production clusters developing there. Therefore, this trend creates an incentive for U.S. companies to offshore some activities.

The United States Is the Largest Global Supplier, Employer, and Market for Software Services

Although the industry is globalizing, the United States has maintained its leadership in the development and expansion of the software services industry. U.S. companies are global leaders in the packaged software and custom software services segments of the industry. Although statistics on software services are more limited than for semiconductor manufacturing, indicators show that the United States is a leading developer and consumer of software globally. U.S. production and employment data show that the industry has generally rebounded after declining during the 2001 recession. Also, while both imports and exports have grown rapidly, the United States maintains a trade surplus in software services.

The United States Is a Leading Software Developer and the Largest Supplier in the World

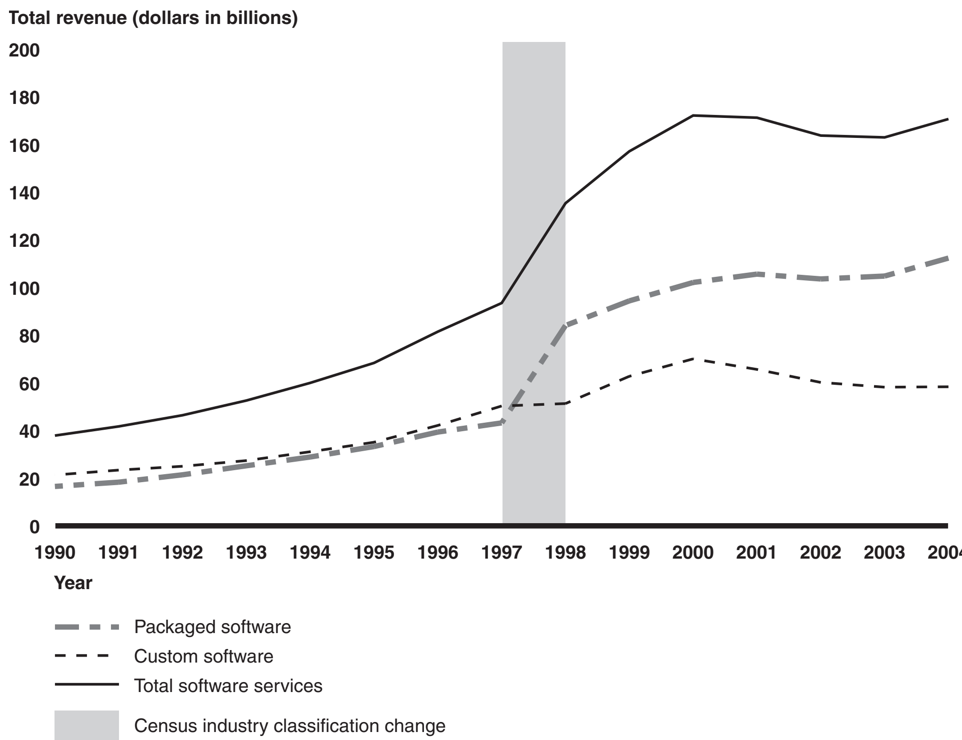
The U.S. software industry is the largest in the world and plays a leadership role in the global market for software services. U.S. companies are disproportionately ranked among the largest in the world, both in terms of revenues and numbers of top firms.[18] U.S. companies also benefit from the large U.S. domestic market, which by one industry estimate accounts for about 50 percent of global demand for packaged software and about 40 percent of global demand for custom software services. U.S. software companies are also widely considered leaders in the development and delivery of leading-edge software services. According to industry experts, much of the development of these services takes place in the United States, although larger companies also employ teams of developers worldwide.

U.S. Software Production Has Rebounded from the 2001 Recession

Although the industry experienced a downturn during the 2001 recession, it has since begun to recover. As figure 8 shows, the U.S. software industry grew rapidly through the late 1990s, declined during the 2001 recession and, as of 2004, had rebounded to its peak in 2000 based on industry revenue. Packaged software appears to be leading the rebound, while custom software revenues have remained flat since 2002.

[18]According to the Association of Computing Machinery (ACM), an industry association, U.S. firms make up 11 of the top 15 software companies (both packaged and custom services), with the remaining 4 companies from Germany, Japan, and France. See ACM, *Globalization and Offshoring of Software: A Report of the ACM Job Migration Task Force* (www.acm.org, March 2006).

Figure 8: U.S. Software Industry Revenues, 1990–2004



Source: U.S. Census Bureau, Services Annual Survey.

Note: Census industry classification changed from the Standard Industrial Classification (SIC) system in 1997 to the North American Industry Classification System (NAICS) in 1998. Therefore, there is a break in the series as indicated by the shaded area and dotted trend lines. Also, data on value-added for software services industries are not collected by the Bureau of the Census. Total revenue includes exports and is reported in current U.S. dollars (not adjusted for inflation). Price indices at this level of industry detail were not available. However, we did examine how the results would change using a higher level industry price index to adjust for inflation (or deflation). The higher level industries (publishing, which includes packaged software, and information and data processing services, which include custom software) experienced some inflation over this period and, therefore, after adjusting for inflation the growth in the software industry was somewhat reduced. However, our observations on the both the growth of the industry and its rebound since the recession were still consistent with the inflation-adjusted data.

U.S. Employment in Computer Specialist Occupations Has Grown Overall Since the 2001 Recession

U.S. software industry employment is the largest in the world. According to one industry estimate, U.S. software employment makes up roughly about half of the global workforce in packaged software and about a third of the workforce employed in IT services industry, which includes custom software services.[19] As a group, software occupations, or computer specialists as designated by the Department of Labor's Bureau of Labor Statistics (BLS), experienced relatively large gains in both employment and hourly wages from 2001 to May 2005 (the most recent time period for which comparable occupation-based data are available).[20] This period largely coincided with an economic recovery following the 2001 recession.[21] Table 2 compares changes in employment and hourly wages for nine computer specialist occupations and that of all U.S. occupations. Seven of the occupations saw employment growth ranging from 1.1 percent to 46.9 percent compared to 1.8 percent for all U.S. occupations. Employment for two occupations (computer programmers and database administrators[22]) declined by 22.4 percent and 4.7 percent, respectively, from 2001 to May 2005. The wages for these occupations also increased more slowly than the wages for all U.S. occupations. Hourly wages for five occupations increased more slowly than the wages for all U.S. occupations, increasing by 3.5 percent to 10.5 percent compared with 11.4 percent for all U.S. occupations. Wages for four occupations, however, increased faster than the wages for all U.S. occupations, rising by 12 percent to 22.2 percent.

[19]See McKinsey Global Institute, *The Emerging Global Labor Market: Part I—The Demand for Offshore Talent in Services* (www.mckinsey.com/mgi: June 2005).

[20]In November 2002, BLS's Occupational Employment Statistics Survey changed from an annual survey to a semiannual survey.

[21]The National Bureau of Economic Research's Business Cycle Dating Committee determined that a trough in business activity occurred in the U.S. economy in November 2001 marking the end of the recession that began in March that year.

[22]Database administrators identify user requirements and set up and administer computer database systems.

Table 2: Changes in Hourly Wage and Employment for U.S. Computer Specialist Occupations

Occupations	Hourly wage (May 2005)	Percentage change in hourly wage (2001-May 2005)	Number of jobs (May 2005)	Percentage change in employment (2001-May 2005)
Computer and information scientists, research	$45.21	22.2%	25,890	1.1 %
Computer software engineers, systems software	40.54	13.2	320,720	22.6
Computer software engineers, applications	38.24	9.9	455,980	26.1
Computer systems analysts	33.86	10.5	492,120	9.8
Computer programmers	32.40	7.2	389,090	-22.4
Database administrators	31.54	12.3	99,380	-4.7
Network systems and data communications analysts	31.23	7.7	185,190	46.9
Network and computer systems administrators	30.39	12.0	270,330	18.6
Computer support specialists	20.86	3.5	499,860	1.3
All U.S. occupations	$18.21	11.4%	130,307,850	1.8%

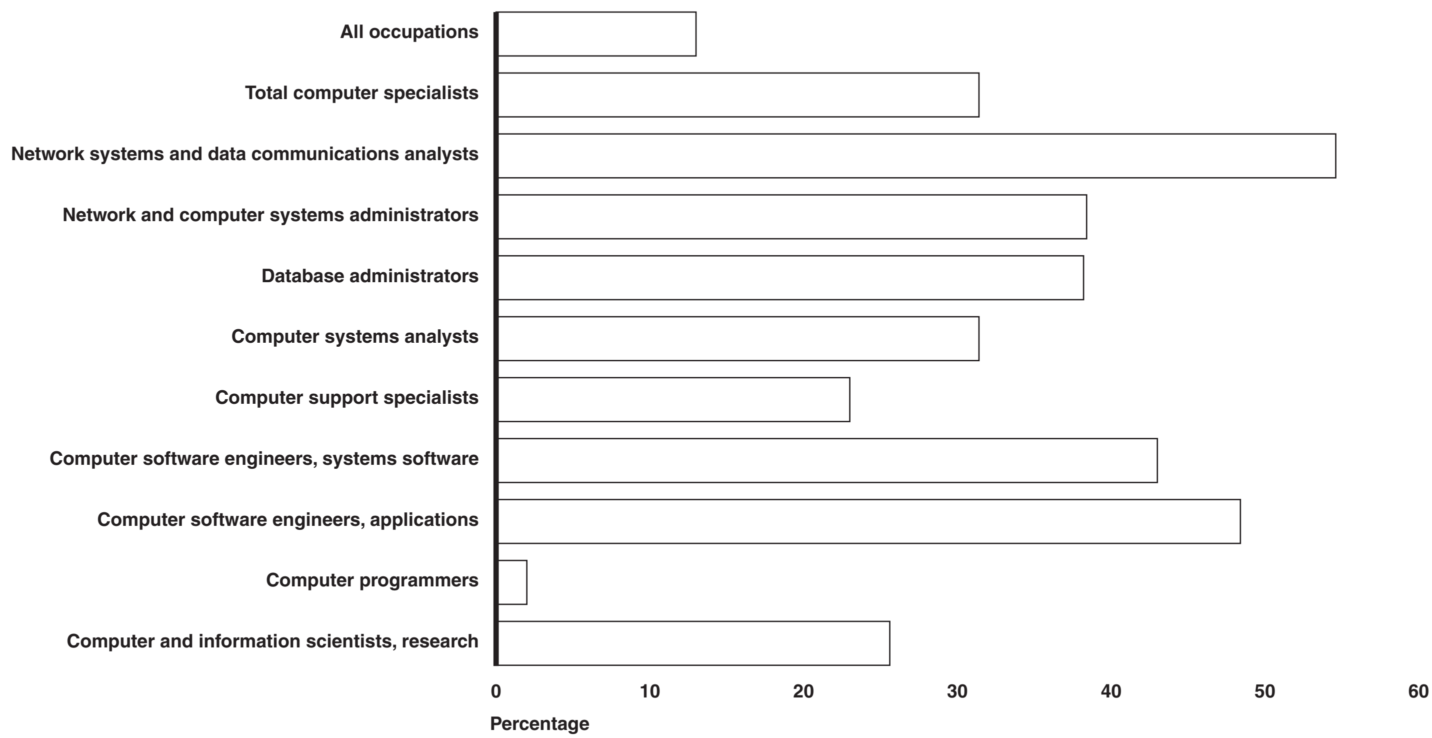
Source: Occupational Employment Statistics Survey, BLS.

Note: Occupations are ranked by hourly wage.

Computer software engineers (including systems software and applications engineers, two high-wage occupations) saw modest increases in wages but relatively large increases in employment, growing by 22.6 and 26.1 percent, respectively. Computer software engineers design, develop, and test the software and computer systems, applying computer science, mathematics, and engineering expertise. The integration of Internet technologies and the rapid growth in e-commerce have led to a rising demand for computer software engineers. Although hourly wages of network systems and data communications analysts increased by a relatively low 7.7 percent, their job growth was the largest of all computer specialist occupations at 46.9 percent. This group of computer specialists designs, tests, and evaluates network systems and other data communications systems.

According to BLS, employment in computer specialist occupations, apart from computer programmers, is projected to grow much faster than overall U.S. employment.[23] Although total U.S. employment is projected to grow 13 percent over the 2004 to 2014 period, employment of computer specialists is projected to grow 31.4 percent (see fig. 9). BLS projects that the demand for computer-related jobs is likely to increase as employers continue to adopt and integrate increasingly sophisticated and complex technologies. Growth, however, will not be as fast as the previous decade, as the software industry matures, and as routine work is increasingly offshored.

Figure 9: Projected Rate of Job Growth for Computer Specialist Occupations, 2004–2014



Source: BEA.

[23]Daniel Hecker, "Occupational Employment Projection to 2014," *Monthly Labor Review*, November 2005, Bureau of Labor Statistics.

Projected job growth for computer software engineers and network systems and data communications analysts is especially robust. The BLS's *Occupational Outlook Handbook* suggests that demand for workers with specialized technological skills is expected to increase sharply as employers use and improve the efficiency of new technologies. As the race for increasingly sophisticated technological innovations continues, the need for more highly skilled workers to implement these innovations will continue. More highly skilled computer specialists will be needed as businesses and other organizations try to manage, upgrade, and customize their increasingly complicated computer systems. Computer specialists who have a combination of strong technical and good interpersonal and business skills will be in demand.

Unlike other computer specialists, job growth of computer programmers is expected to lag significantly behind the growth in overall U.S. occupations. Programmers are projected to grow only by 2 percent from 2004 to 2014. Because computer programming requires little localized or specialized knowledge, computer programming can be performed anywhere in the world and transmitted electronically. Consequently, programmers potentially face a higher risk of having their jobs offshored than other computer specialists such as software engineers, who are involved in more complex information technology functions. Another factor limiting job growth in computer programming is progress in programming technology. Computer software has become increasingly sophisticated, enabling users to write basic code without programmers' involvement for routine programming.

The United States Maintains a Trade Surplus in Software Services Trade, but Imports Are Growing

The United States is a net exporter of software services and has maintained this trade surplus for several decades. Although U.S. exports are rising rapidly, imports are also increasing in this category. Canada is the largest supplier of imported computer and data processing services to the U.S. market but, as we have previously reported, India is rapidly growing as a supplier of these services.[24] Figure 10 shows U.S. exports and imports of computer and data processing services, the category that includes both custom and packaged software services (as defined by BEA) since 1986.

[24]See GAO-06-116. This report also highlights limitations in the data of services trade and the significantly larger exports statistics reported by India.

Figure 10: U.S. Unaffiliated Exports and Imports in Computer and Data Processing Services, 1986–2004

Source: BEA.

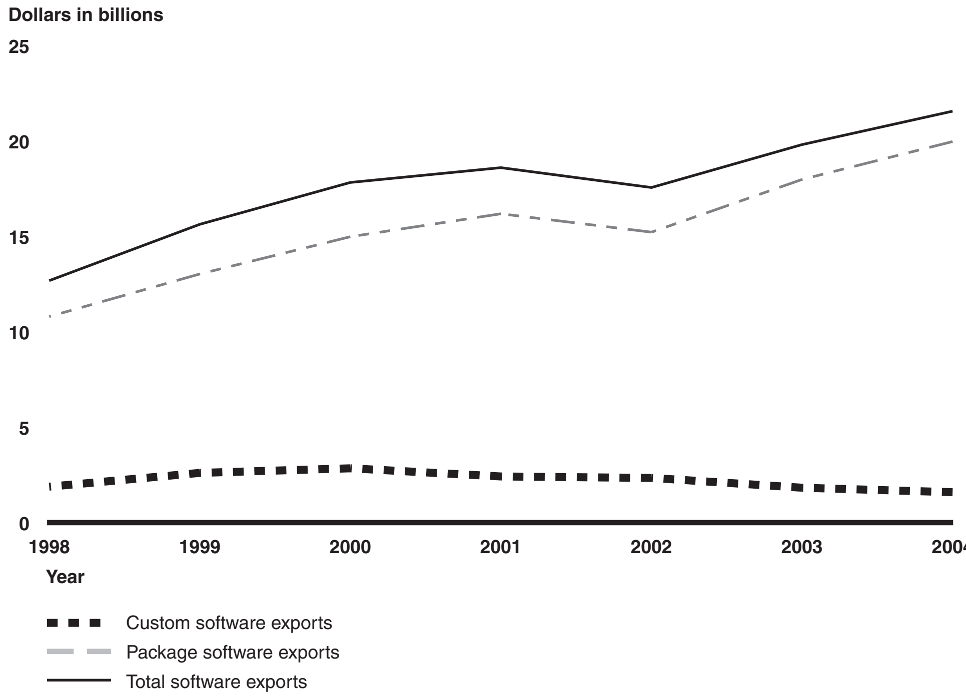
Note: The values are for unaffiliated transactions—sales between companies located in the United States and unrelated third party providers or purchasers located abroad. Statistics on both affiliated and unaffiliated transactions in this product category are only available since 2001. However, these data show that United States also maintains a trade surplus in overall (affiliated and unaffiliated) computer and data processing services from 2001-2004.

U.S. exports of software services make up about 13 percent of overall U.S. software revenues according to the U.S. Census Bureau (Census). However, most export revenue is derived from packaged software exports. These Census statistics show a much larger value of exports than the BEA trade in services statistics.[25] As shown in figure 11, U.S. companies report

[25]BEA reported U.S. affiliated and unaffiliated exports of computer and information services (which includes computer and data processing services) at $8.5 billion in 2004. Census reported U.S. exports by custom computer programming services and software publishers at $21.6 billion. Some of this discrepancy is accounted for by differences in the treatment of packaged software, classifications, and survey samples. For example, BEA's statistics exclude computer software that is physically shipped and considered a good rather than a service.

nearly $22 billion in exports of software services, primarily comprising about $20 billion in U.S. package software exports.

Figure 11: U.S. Exports of Software, 1998-2004



Source: Census.

Information on trade in software services is significantly more limited than information on trade in semiconductors. Although both BEA and Census collect statistics on software trade, as demonstrated by the previous two figures, the data are available only for the aggregate categories shown. In comparison, for semiconductors, over 230 individual semiconductor goods are identified by Census as they cross international borders. In addition, most countries in the world utilize the same goods classification system, known as the Harmonized System, to record trade in goods. However, efforts to create and utilize detailed and compatible classification systems across countries for services such as software are still relatively new.[26] Part of the challenge in collecting detailed statistics on services industries, such as software, derives from the "intangible" nature of many services—they are not necessarily physical products—and the fact that they don't cross customs borders like goods. Rather, services data is collected by surveying companies for information on their payments or receipts for services. In addition, services can be delivered to the customer through many different channels, including licensing agreements, imbedded in goods such as computers, or a commercial presence such as a foreign subsidiary.

The U.S. Semiconductor and Software Industries Benefit from the Large, Innovative U.S. Economy

The United States maintains substantial advantages as a large, technologically sophisticated economy. The U.S. high-technology industries, such as semiconductors and software, have benefited from a U.S. economic environment that supports innovation—world-class universities and research centers, a talented labor pool, and high levels of spending on R&D. The industries also benefited from a competitive U.S. business environment, an efficient legal system for contracts and intellectual property protection, and a large domestic market.[27]

University and Research Centers, Talented Labor, and R&D Investment Have Helped Foster Innovation

Although a wide range of causes and circumstances leads to new innovations, certain enabling factors create an environment that fosters new ideas and their development. These include (but are not limited to) such factors as the higher education system and related research centers, pools of talent available, and the investments in research and development.[28]

[26]For example, see the discussion of the discrepancies between U.S. and Indian services trade data in GAO-06-116.

[27]However, measuring the individual contribution of any one of these factors on the development of the semiconductor and software industries, as well as their future importance to these industries, is beyond the scope of this report.

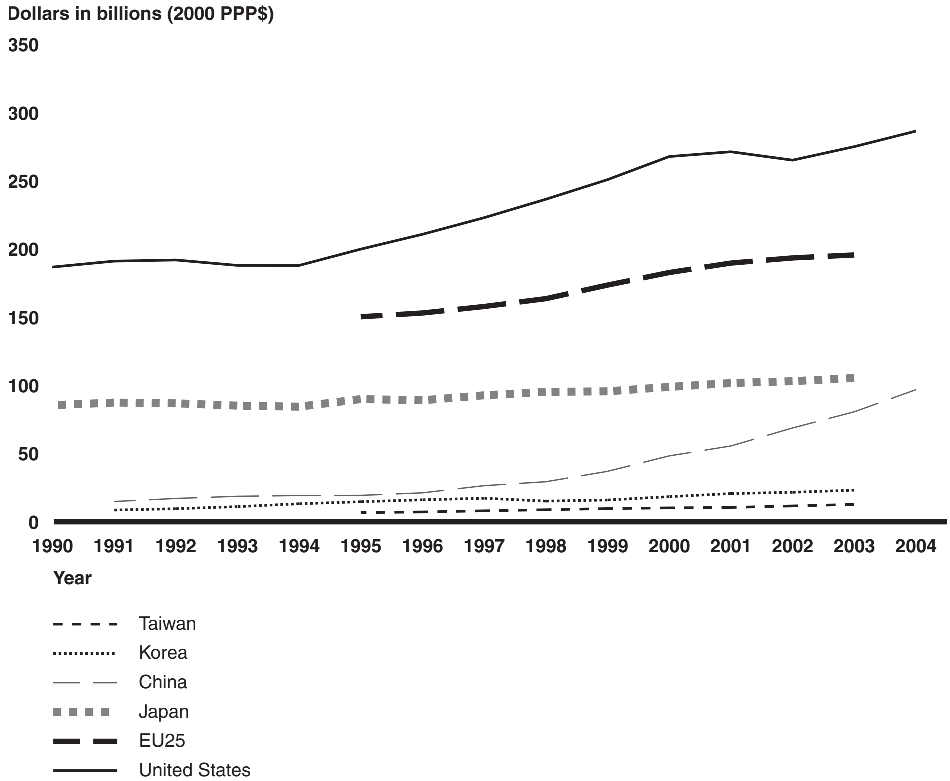
[28]Although we discuss several indicators of innovation in this section, there are a variety of measures available. See for example, National Science Board, *Science and Engineering Indicators, 2006* (Washington, D.C.: National Science Foundation, 2006) available at www.nsf.gov. Also, it is important to note that each of these indicators provides only a limited measure of certain aspects of innovation, which is a broad and elusive concept. For a comparison of R&D globalization across countries, see Swedish Institute for Growth Policy Studies, *The Internationalization of Corporate R&D* (Stockholm, ITPS, 2006) available at www.itps.se.

The U.S.'s world-class higher education system and research institutes create communities for researchers and educators and are widely considered a key competitive advantage. The higher education system in the United States includes many universities that are ranked among the best in the world in terms of research, education, and entrepreneurship. Also, a large number of top applicants from around the world apply for undergraduate, graduate, and postdoctoral study. More specifically, U.S. computer science and engineering programs—of particular importance to high-technology industries such as semiconductors and software—are leaders in their fields. The higher education system has provided both a strong research environment and a pool of talented labor—both native born and foreign students who remained after education.

A second factor that fosters innovation is the quality and number of available researchers and other skilled labor. Countries with larger and more talented labor pools are more likely to foster and sustain innovation. The United States has a world-class talent pool that includes both technical and managerial talent. The United States has the largest number of researchers worldwide, with about 1.3 million, followed closely by the European Union (EU-25), according to data from the Organization for Economic Cooperation and Development. China, ranked third, has rapidly increased the number of its researchers to surpass Japan. Although the quality of these researchers is not captured by the indicator, it does show the growing size of the Chinese research community.

A third factor that fosters innovation is a country's investment in research and development. This investment may come from several sources, including the government, academia, and business. U.S. expenditures on R&D are the largest in the world and have continued to grow over time (see fig. 12). Currently, the United States spends about 2.7 percent of its gross domestic product on R&D expenditures, compared with about 3.2 percent for Japan and 1.4 percent for China. For certain industries such as semiconductors, early investments by the federal government—the military, in particular—have been key in the initial development of the industry. However, this role may change over time. For the United States, the increase in R&D expenditures over the past decade has been driven by the business community, while the total amount of federal R&D has grown much more slowly in comparison.

Figure 12: Gross Domestic Expenditures on Research and Development by Country, 1990–2004



Source: Organization for Economic Cooperation and Development, *Main Science and Technology Indicators*, 2005.

Note: 2000 PPP$ refers to gross expenditure data converted from national currencies (e.g., the Yen) into inflation-adjusted year 2000 U.S. dollars based on purchasing power parity (PPP) conversion factors. PPP conversion factors take into account differences in the relative prices of goods and services and differ from market exchange rates. Data on EU-25 R&D expenditures prior to 1995 are not available.

While the United States has generally maintained a strong advantage in areas that foster innovation, several studies have recently raised questions about continued dominance of the United States in cutting-edge innovation.[29] They cite a range factors that indicate the rise of other competitors in traditionally U.S.-dominated areas. For instance, changes in U.S. visa and immigration requirements have been cited as hampering the number of foreign students, researchers, and high-tech workers who are attracted to the United States and allowed to reside here.[30] At the same time, other countries' university systems are increasingly competing with the United States to attract the most qualified students and researchers. According to these studies, these changes have led to a decline in the number of university applications from foreign students. Similarly, other countries have liberalized their economies and provided greater opportunities for higher skilled workers. Therefore, more students and researchers, including those from India and China, who may have once stayed in the United States have an incentive to return to their native countries.

Business Environment, Legal System, and Domestic Market Affect Commercialization of Innovation

In addition to an environment for fostering innovation, countries need to be able to commercialize these innovations to affect the wider economy. Several factors contribute to a U.S. competitive environment that encourages innovation to be commercialized. First, the business environment includes relatively competitive product markets that encourage businesses to take new products to market in order to gain advantage over rivals, while also allowing new entrants to challenge existing companies. The United States also has a relatively efficient financial system, including venture capital markets that fund new innovations and start-ups in high-technology industries. The U.S. legal and regulatory environment, including its intellectual property protections

[29]See, for example, *Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, D.C.: National Academy Press, February 2006), *America's Pressing Challenge – Building a Stronger Foundation: A Companion to Science and Engineering Indicators 2006* (Washington, D.C.: National Science Board, January 2006), and *Sustaining the Nation's Innovation Ecosystems, Report on Information Technology Manufacturing and Competitiveness*, (Washington, D.C.: President's Council of Advisors on Science and Technology, January 2004).

[30]For additional information of the U.S. visa program, see GAO, *Border Security: Streamlined Visas Mantis Program Has Lowered Burden on Foreign Science Students and Scholars, but Further Refinements Needed*, GAO-05-198 (Washington, D.C.: Feb. 18, 2005) and GAO, *Border Security: Improvements Needed to Reduce Time Taken to Adjudicate Visas for Science Students and Scholars*, GAO-04-371 (Washington D.C.: Feb. 25, 2004).

(such as patents), allows individuals and companies to be rewarded for their investment in innovation. Finally, the large U.S. domestic market provides an avenue for companies to sell new products to a wide range of sophisticated customers. The U.S. economy is by far the largest in the world, and per capita income is also one of the highest in the world. This creates an environment for U.S. companies to develop and sell new products profitably. In addition, companies that are close to their customers are able to spot new trends and preferences in demand and cater to them. This is particularly true in high-technology industries in which the product life cycle is relatively short and profit margin for older products declines quickly.

Concluding Observations

The past decade's revolution in telecommunications and related advances in supply chain management capabilities have deeply affected the business models for both the semiconductor manufacturing and software services industries. These industries' overall business model is now a global one, in which U.S. firms regularly consider a wide range of locations for their operations and source different parts of their operations wherever the advantages are most compelling. For the semiconductor industry, firms initially offshored labor-intensive assembly activities to cut labor costs, but more recently firms have offshored other activities for various reasons, including proximity to other industry suppliers, closer relations with foreign customers, benefits offered by foreign governments, and the availability of both skilled and unskilled human capital. In the software industry, the offshoring trend is more recent, but the motivations are similar.

For software services, however, an important difference may be the possible speed and scale of employment shifts. Software services offshoring, compared with semiconductor manufacturing offshoring, does not need the same physical infrastructure, such as ports, roads, and factories, and thus can be set up more quickly. It is more labor intensive than capital intensive, and thus may be more sensitive to wage differentials. In addition, service occupations related to software programming are large in comparison to manufacturing jobs in the semiconductor industry. In semiconductor manufacturing, there was relatively slow movement up the value chain as firms invested in the overseas workforce and factory facilities. India's software industry development has advanced more quickly, with rapid technological changes bringing large numbers of highly educated, but underused, English-speaking workers to the doorstep of firms willing to operate from India. The data available to monitor the scale of services offshoring, unfortunately, are much more limited than those available for following trade in manufactured products. Semiconductor products, for example, can be identified and inspected at U.S. borders, whereas software imports and exports can be transmitted almost instantaneously over the Internet.

Government policies also played important, but different, roles in Taiwan, China, and India; however, all three governments have placed high importance on education. In recent years, China has been transforming large parts of its coastal cities through massive infrastructure investments and has provided more targeted inducements for firms, such as support for science and technology parks and various types of financial assistance. India liberalized parts of its central government apparatus in the early 1990s, but its investment in physical infrastructure such as roads and ports has been much more limited, although India has also supported its science parks and put in place advanced telecommunications infrastructure improvements. These incentives for software exporters appear to have been well targeted.

The comparison of these two offshoring experiences offers some insights for U.S. policies. Clearly, a large and well-educated population appears to be a central element to success in both semiconductor manufacturing and software services activities. Also, technological changes have impacts that are not always predictable and, in a now closely-connected global business world, such changes can have continuing dynamic effects on U.S. industries. India may have neither fully predicted or planned its current strengths in software services, nor foreseen how its pool of native English speakers could be such an asset, but it now realizes the importance of enhancing its strengths in these areas. In addition, ambitious national goals—whether China's semiconductor development road maps or Indian businesses' long-term strategies—are additional elements in the mix of factors that will shape these countries' futures and will pose competitive challenges to U.S. firms.

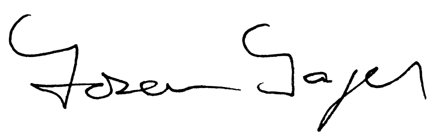
As numerous recent studies have reported, the ability of the United States to continue to compete at the most advanced levels in high technology industries depends on a range of reinforcing factors: high-level R&D investment by companies and government, innovative academic environments attracting and training the highest-skilled researchers, a competitive business environment that fosters development and commercial application of new technologies, and a flexible and skilled workforce. These factors are being nourished in China, Taiwan, and India, as these countries seek to move further up the value chain and to "leapfrog" advanced country capabilities where possible. Indeed, these countries have modeled their industry development strategies on various aspects of the U.S.'s successful model. The United States is an integral part of this dynamic world economy—in which it will be important for U.S. businesses and policymakers to keep alert to technological changes, to anticipate competitor countries' strategies, and to preserve and enhance the elements of the innovation environment that helped make the United States a model.

Agency Comments and Our Evaluation

We provided a draft of this report to the Departments of State and Commerce for their review and comment. The Department of State did not provide comments. We received written comments from the Department of Commerce, which agreed our findings. (See app. IV.) The Department of Commerce also provided technical comments, which we incorporated into the report, as appropriate.

We are sending copies of this report to interested congressional committees and the Departments of State and Commerce. We also will make copies available to others on request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-4128 or yagerl@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report are listed in appendix V.



Loren Yager
Director, International Affairs and Trade

List of Committees

The Honorable Max Baucus
Ranking Minority Member
Committee on Finance
United States Senate

The Honorable Henry A. Waxman
Ranking Minority Member
Committee on Government Reform
House of Representatives

The Honorable Charles Rangel
Ranking Minority Member
Committee on Ways and Means
House of Representatives

The Honorable Bart Gordon
Ranking Minority Member
Committee on Science
House of Representatives

Scope and Methodology

This report discusses (1) the development of offshoring in semiconductor manufacturing and software services over time, (2) the factors enabling the expansion of offshoring in these industries, and (3) the development of these industries in the United States as they have become more global.

To obtain information about the key developments in the offshoring of semiconductor manufacturing and software services, we reviewed available literature; attended conferences on the subject; and interviewed government officials, representatives of private firms, industry associations, and research organizations in China, India, Taiwan, and the United States. We performed a literature search and obtained information from several research organizations, universities, and industry associations that have published industrywide studies on offshoring and the key developments in both the semiconductor manufacturing and software services industries, including the Association for Computing Machinery; Brookings Institution; Gartner, Inc.; McKinsey and Company; the University of California, Berkeley; Stanford University; Carnegie Mellon University; the Semiconductor Industry Association; and the Information Technology Association of America. We attended conferences on developments in the semiconductor and software services industries and the general offshoring phenomenon. We interviewed researchers at private research organizations, industry experts at the U.S. Department of Commerce and the U.S. International Trade Commission, and government officials from India and Taiwan. In addition, we met representatives of private sector firms in the semiconductor and software services industries in China, India, Taiwan, and the United States. We also interviewed representatives and obtained data from organizations representing semiconductor and software services firms and workers, including the Semiconductor Industry Association, the National Association of Software and Service Companies, and the Information Technology Association of America. We discussed with these sources the historical changes that have occurred broadly in the computer hardware industry, particularly with respect to China and Taiwan, and the software services industry, particularly with regard to India.

To determine the factors that have contributed to offshoring in semiconductor manufacturing and software services, we conducted a review of available literature and interviewed representatives of private sector firms, semiconductor and software services industry associations, business associations, and research organizations (see above). In addition, we interviewed industry experts within the U.S. government and the governments of India and Taiwan. We met with and reviewed relevant literature from researchers who have published on the offshoring phenomenon and the factors contributing to global developments in semiconductor manufacturing and software services; including experts from the Brookings Institution; the Institute for International Economics; the Milken Institute; and the University of California, Berkeley. We interviewed representatives of private sector firms in China, India, Taiwan, and the United States that have globally sourced semiconductor manufacturing and software services; trade and industry experts in the U.S. Department of Commerce; and the governments of India and Taiwan. In addition, we interviewed representatives of business and industry associations, such as the Federation of Indian Chambers of Commerce and Industry, the U.S.-Taiwan Business Council, and the Semiconductor Industry Association.

To determine developments in the semiconductor and software services industries in the United States as they have become more global, we examined available government data, information from experts in both the semiconductor and software services industries, and other private sector research. We obtained U.S. international trade data from the Bureau of Economic Analysis (BEA) and the U.S Census Bureau. We also obtained foreign countries' international trade data through the United Nations and a private company, Global Trade Information Services. We obtained foreign direct investment data from BEA and domestic production data from Census. To assess the limitations and the reliability of various data series, we reviewed technical notes and related documentation and met with officials from BEA and Census, as well as individuals in the private sector familiar with these data. In addition, we reviewed relevant research studies and obtained data from several private sector entities. Although we do not report these data directly, we used them to corroborate information from other sources. To determine employment trends in the semiconductor and software services industries, we analyzed available U.S. government employment data from the Bureau of Labor Statistics (BLS). We cross-checked various employment data and reviewed technical notes in BLS publications to assess the limitations and reliability of these data. We also discussed the limitations and reliability of BLS data with BLS officials. We determined that the data we used in this report to show the development and trends in the semiconductor and software industries were sufficiently reliable for these purposes.

We conducted our review from October 2005 through August 2006 in accordance with generally accepted government auditing standards.

U.S. Multinational Companies' Investment and Operations in the Semiconductor and Software Industries

U.S. multinational companies' worldwide investments and operations (including production, employment, and research and development (R&D) have played an important role in the globalization of the semiconductor and software industries.[1] U.S. statistics show that overall multinational corporation (MNC) investments have still tended to be in developed economies, rather than in developing economies such as India and China. However, certain manufacturing sectors such as the computer and electronic products industry (including semiconductors) have a relatively higher share of investment, production, and employment in developing countries. In particular, U.S. companies' investments and production in this industry are relatively higher in the Asia-Pacific region (particularly Singapore) than other industries. Employment is even more concentrated abroad—likely due to the movement of more labor-intensive production operations overseas in order to reduce costs. Conversely, research and development expenditures are much more concentrated in the United States than they are in foreign affiliates.

In recent years, U.S. Investment Offshore Has Been Relatively Stable and Has Been Larger in Singapore and Malaysia, Than in Taiwan and China

U.S. direct investment abroad statistics show that overall U.S. investment (across all industries) in developing country markets is still a relatively small share of total U.S. direct investment abroad (less than 1 percent of the total each for India, China, and other developing countries, except Mexico and Brazil), according to statistics from the Bureau of Economic Analysis (BEA).[2] However, within the computer and electronic products industry (which includes semiconductors),[3] Singapore was the most significant Asia-Pacific country accounting for 15 percent of U.S. global

[1]Investment abroad—establishing a foreign located affiliate of a parent company—is one means of offshoring parts of the production process. The other main means is to contract with an independent company, which is not captured in investment statistics. In addition, companies may devise hybrids of these two approaches, such as establishing a joint venture. Information provided in this appendix only relates to offshoring through a foreign affiliate and not offshoring that may occur through an unaffiliated provider that replaces domestic production and employment. For more information on definitions of offshoring, see GAO-04-932, appendix II.

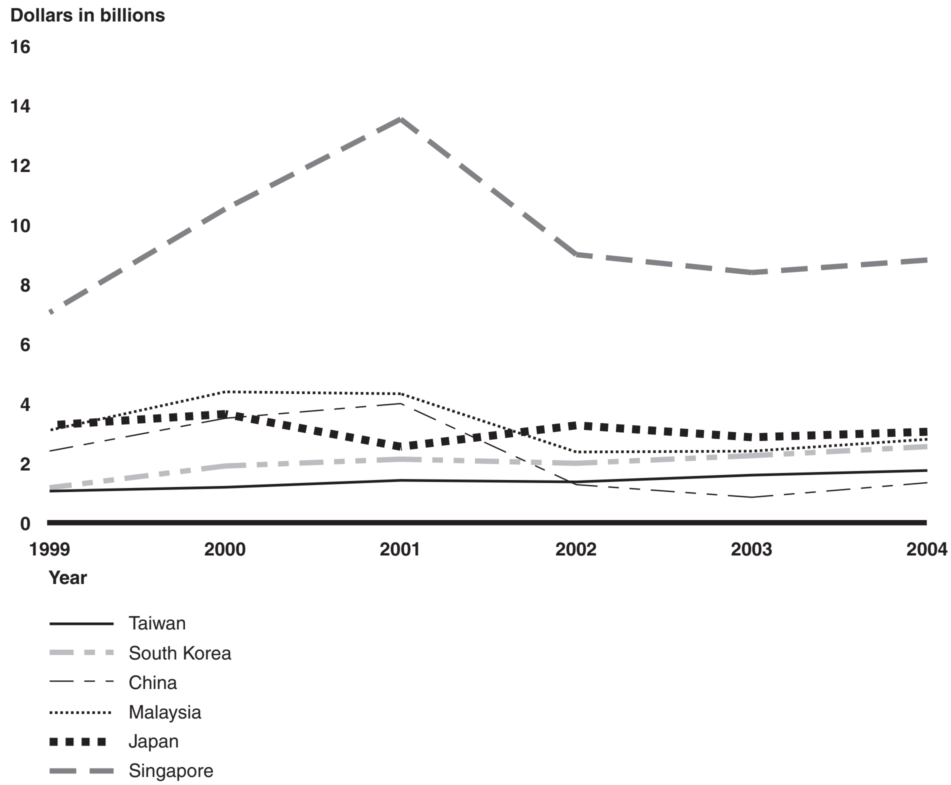
[2]Direct investment abroad statistics on an historic cost basis, as reported here, will exclude the value of U.S. investments in particular countries if that investment is made through holding companies located in other countries. The U.S. investment will be attributed to the country of the holding company.

[3]Detailed direct investment abroad statistics on the semiconductor industry by country are not available.

investment in that industry as of 2004.[4] Malaysia and Japan were next with about 5 percent; followed by Korea (4 percent); Taiwan (3 percent); and China, Hong Kong, and the Philippines (2 percent, each). Figure 13 shows the value of U.S. foreign direct investment (FDI) from 1999 to 2004 in this industry for selected Asian countries. As figure 13 shows, Singapore accounted for $8.8 billion in U.S. FDI in 2004 (down from $13.5 billion in 2001), or about 15 percent of the global total in this industry. Interestingly, the value of U.S. FDI in China in this sector has fallen since 2001—more significantly than for other countries, except Singapore. These data represent the accumulated investments (stock) made by U.S companies in the computer and electronic products industry. As discussed in this report, U.S. companies moved labor-intensive assembly and testing operations overseas over the past several decades. Also, U.S. exports of semiconductor wafers were largest to Malaysia, Korea, Taiwan, Philippines, and China. This reflects the production process in which fabricated wafers are then sent overseas for final assembly and test by U.S. companies' affiliates (as well as unaffiliated contractors).

[4]Singapore was the largest location of U.S. direct investment abroad as of 2004 in this industry. Ireland (12 percent), Canada (10 percent), and Italy (10 percent) were the next largest locations by value.

Figure 13: U.S. Direct Investment Abroad in the Computers and Electronic Products Industry, Selected Asian Countries, 1999–2004

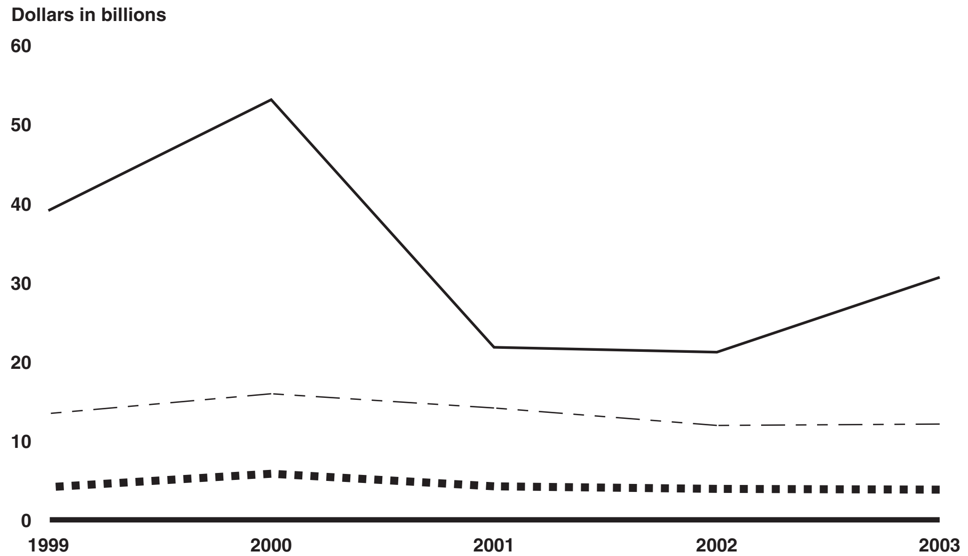


Source: BEA.

Note: U.S. direct investment abroad is the stock of U.S. investments in a particular country valued in a historical cost basis. The computer and electronic products industry includes semiconductor production. However, detailed investment statistics by country for the semiconductor industry are not available.

Within the semiconductor industry, the majority of U.S. companies' global production (as measured by value-added) remained in the United States, although the share declined during the recent recession. As figure 14 shows, semiconductor value-added by U.S. parents (U.S. operations) took a steep decline in 2001, remained flat in 2002, and rebounded somewhat in 2003. Value-added by U.S. companies' affiliates abroad accounted for about 28 percent of U.S. MNC's global production, while the Asia-Pacific region (excluding Japan and Australia), in particular, accounted for about 9 percent of global production.

Figure 14: Value-added in Semiconductors—U.S. Parents and MOFAs (including Asia-Pacific, excluding Japan and Australia)



	1999	2000	2001	2002	2003
MOFA value-added—Asia (excluding Japan/Australia)	13,419	15,920	14,123	11,919	12,091
MOFA value-added—all countries	4,122	5,818	4,230	3,908	3,812
Parents value-added	39,053	53,057	21,788	21,172	30,625

MOFA value-added—Asia (excluding Japan/Australia)
MOFA value-added—all countries
Parents value-added

Source: BEA.

Note: MOFA refers to majority-owned foreign affiliates. Data for 2003 are preliminary.

Global Semiconductor Employment by U.S. Companies Is Roughly Split between Their U.S. Operations and Offshore Locations

U.S. MNCs that operate affiliates offshore have overall split their employment between their U.S. operations and their foreign affiliates. According to data from BEA, about 53 percent of MNC's global semiconductor employment was located in offshore affiliates in 2003, up from 49 percent in 1999.[5] As previously discussed, this reflects the trend begun in 1960s of U.S. companies' offshoring much of their labor-intensive assembly and testing operations to lower wage countries, particularly in Asia. BEA statistics also show that a relatively higher share of U.S.

[5]BEA data include total employment in U.S. MNC's parent operations (located in the United States) and majority-owned foreign affiliates (located in foreign countries).

employment in semiconductor manufacturing is concentrated in Asia compared with other industries. Similarly, U.S. MNCs in computer and electronic product manufacturing industries (of which semiconductors is a part), in general had relatively higher shares of their global employment located abroad (about 38 percent) than other information and communications technology industries such as computer system design and related services (35 percent), as well as across all industries (28 percent) in 2003.

Employment statistics from the Semiconductor Industry Association (SIA) show a similar pattern for U.S.-based companies.[6] According to SIA, about 54 percent of U.S. companies' semiconductor employment was located in North America (mainly the United States) in 2004. This is down from a peak of about 60 percent in 1998 but still higher than in the 1980s and 1990s, which was between 45 and 50 percent. In addition, about 28 percent of U.S. companies' North American workforce was engaged in R&D in 2004. According to industry experts, a much higher share of U.S. companies' R&D employment is based in the United States, rather than offshore.

U.S. Companies Investments in Overseas Affiliates to Supply Software Services Still Relatively Low

As discussed above, U.S. direct investment abroad statistics show that overall investment (across all industries) in developing country markets is still a relatively small share of total U.S. direct investment abroad. This is also generally true in services industries that include software services.[7] For example, U.S. direct investment in India in the information sector and the professional, scientific, and technical services sector are both less than 1 percent of global investment in those sectors. However, investment in Ireland in the information sector accounted for 30 percent of global U.S. direct investment abroad in that sector in 2004. Over time, Ireland has attracted investment by a large number of U.S. companies to produce software for the European Union market.

[6]BEA's statistics capture U.S. MNCs and their majority-owned foreign affiliates in the semiconductor and other electronic components sector. SIA's statistics capture all U.S.-based semiconductor companies (whether or not they have foreign affiliates) and their entire employment abroad (which may include less than majority ownership). The two statistics differ to some degree in terms of their definition of the industry and selection of parent companies and affiliates.

[7]Software publishing that produces packaged software is included in the broad industry sector of Information, while custom software services is included in the broader industry sector of professional, scientific, and technical services. U.S. direct investment data by country are not available below the industry sector level of detail.

Similarly, U.S. multinational companies' operations abroad (including employment) in software services are relatively small compared with the semiconductor industry and the broader electronics hardware industry. For example, table 3 shows that, for semiconductors, over half of U.S. MNC's employment was located in their foreign affiliates (rather than their domestically based parent company). In contrast, services industries such as publishing (which includes packaged software) and computer systems design and related services (which includes custom software) had between one-fifth and one-third of their employment located in their foreign affiliates.

Table 3: Share of U.S. Foreign Affiliates' Employment in Total U.S. MNC Employment Worldwide—ICT Sector Industries, 1999–2003

Industry	1999	2000	2001	2002	2003
ICT-producing industries	55%	53%	51%	49%	49%
Computers and electronic products	43	40	40	39	38
Semiconductors and other electronic components	49	52	53	53	53
Publishing industries (including packaged software)	14	16	17	18	18
Information services and data processing services	29	29	28	28	27
Computer systems design and related services (including custom software	29	31	32	32	35
All industries (total)	**25%**	**25%**	**26%**	**27%**	**28%**

Source: BEA.

Note: Shares are calculated by dividing U.S. foreign affiliates' employment by total U.S. MNC employment, which is the sum of U.S. foreign affiliates and U.S. parent company employment. Data for 2003 are preliminary. ICT-producing industries include computer and electronic products manufacturing, publishing industries (includes software), information and data processing services, and computer systems design and related services.

MNC's Research and Development Relatively Concentrated in U.S. Operations

Compared with production or employment, U.S. MNC R&D expenditures are more concentrated in the United States. As shown in table 4, in 2003 about 14 percent of U.S. MNC R&D expenditures were made through U.S. majority-owned foreign affiliates (MOFAs) out of total MNC R&D expenditures (U.S. parents plus MOFAs). The share was similar for the computer and electronic products industry (about 13 percent) and publishing industries (about 10 percent) but less for semiconductors (8 percent), computer systems design and related services (about 5 percent), and information services and data processing services (1 percent). In comparison, MOFAs accounted for about 26 percent of value-added for all industries, 24 percent for computer and electronic products, and 28 percent for semiconductors. Likewise, MOFAs accounted for 28 percent of employment across all industries, 38 percent for computer and electronic products, and 53 percent of semiconductor employment.

Table 4: U.S. Companies' Foreign Affiliates' Share of Total R&D Expenditures

Industry	1999	2000	2001	2002	2003
Computers and electronic products	11%	13%	13%	13%	13%
Semiconductors and other electronic components	7	8	7	9	8
Publishing industries	N/A	6	6	8	10
Information services and data processing services	N/A	1	1	1	1
Computer systems design and related services	4	4	4	5	5
All industries (total)	**13%**	**13%**	**12%**	**13%**	**14%**

Source: BEA.

Note: Data for 2003 are preliminary. "N/A" indicates that the data have been suppressed by BEA to avoid disclosure of data of individual companies.

Across industries, MNCs spent about 22 percent of MOFA R&D expenditures in the computer and electronic products industry (5 percent in semiconductors alone), making it the third largest industry overall in 2003. Other information and computer technology (ICT) sectors represented very small shares (see table 5). Across major industries, transportation equipment manufacturing accounted for 29 percent of total MOFA R&D expenditures (26 percent of that was autos). The next largest was chemicals with 25 percent of R&D expenditures (of which 21 percent was pharmaceuticals).

Table 5: Share of Selected Industries in Total MOFA R&D Expenditures

Industry	1999	2000	2001	2002	2003
Computers and electronic products	21%	27%	29%	24%	22%
Semiconductors and other electronic components	4	4	4	5	5
Publishing industries	N/A	2	2	3	3
Information services and data processing services	N/A	0	0	0	0
Computer systems design and related services	2	2	2	2	2
All industries (total)	**100%**	**100%**	**100%**	**100%**	**100%**

Source: BEA.

Note: These shares represent the percent of total R&D expenditures abroad for each of the selected industries. Data for 2003 are preliminary. "N/A" indicates that the data have been suppressed by BEA to avoid disclosure of data of individual companies.

Asia-Pacific economies account for a relatively small share of U.S. MNC's R&D expenditures. Except for Japan (7 percent overall and 15 percent in information), Singapore (10 percent in computer and electronic products), and Malaysia (5 percent in computer and electronic products), these countries each accounted for 3 percent or less of MOFA expenditures in ICT-related industries (see table 6). China accounts for about 3 percent of manufacturing, but details are not available for computers and electronic products. India accounts for less than 1 percent of R&D expenditures across most industries (note that in the computers and electronic products and professional, technical, and scientific industries, where amounts were suppressed in 2003 for India, prior years also showed less than 1 percent).

Table 6: Share of U.S. Companies' Foreign Affiliates' R&D Expenditures, by Industry for Selected Asia-Pacific Economies, 2003

Country	All industries	Manufacturing	Computers and electronic products	Information	Professional, technical, scientific
Australia	2%	2%	0%	0%	N/A
China	3	3	N/A	N/A	2
Hong Kong	1	1	N/A	0	1
India	0	0	N/A	0	N/A
Indonesia	0	0	0	0	0
Japan	7	7	6	15	2
Korea, Republic of	1	1	2	N/A	1
Malaysia	1	1	5	0	0
New Zealand	0	0	0	0	0
Philippines	0	0	1	0	0
Singapore	2	3	10	1	0
Taiwan	0	0	0	1	0
Thailand	0%	0%	0%	0%	0%

Source: BEA.

Note: Data for 2003 are preliminary. "N/A" indicates that the data have been suppressed by BEA to avoid disclosure of data of individual companies.

Larger Imports of Information and Communication Goods Drive the U.S. Advanced Technology Product Deficit

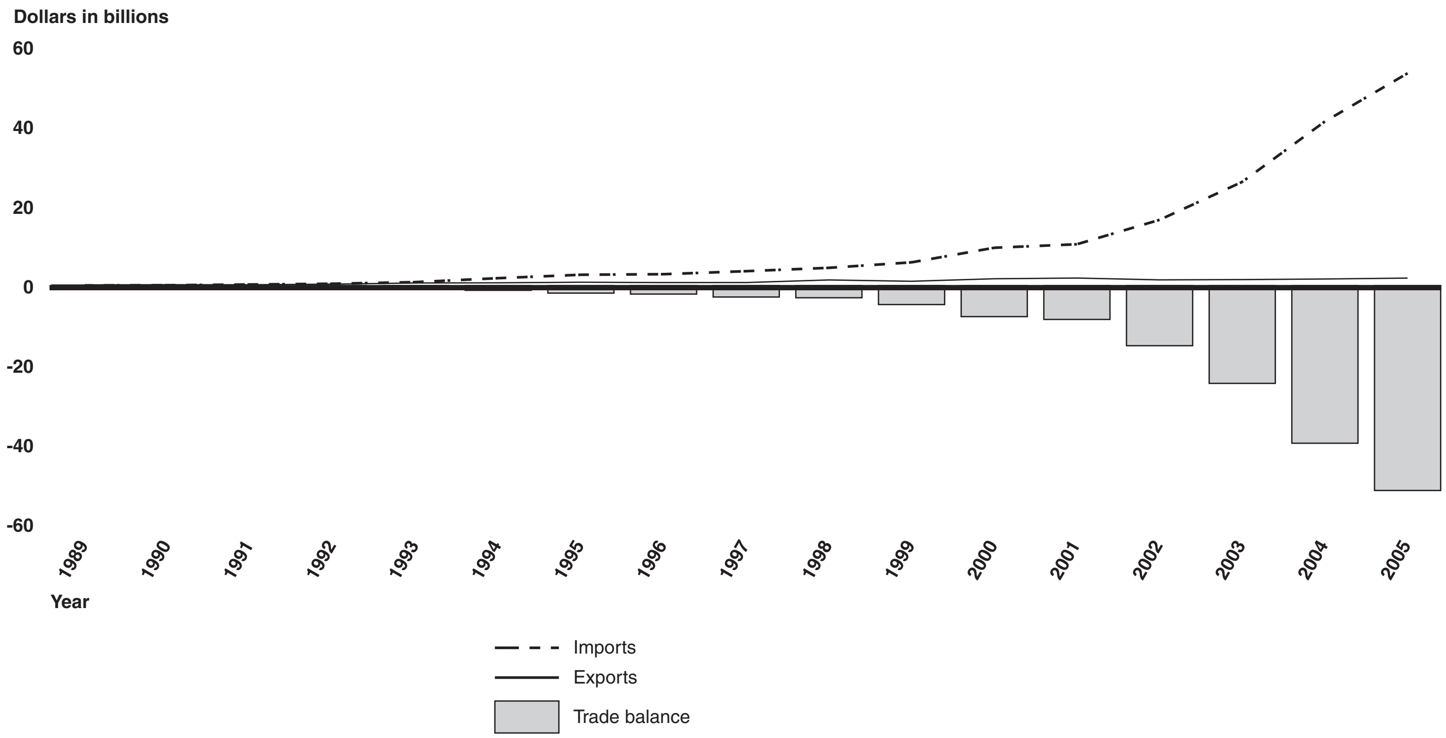
Since 1989, Commerce's Bureau of the Census (Census) has identified products that use leading edge technologies or innovations. Commerce classifies these goods as Advanced Technology Products (ATP). Currently, Census identifies about 500 of some 22,000 10- digit commodity U.S. merchandise trade classification codes as ATP codes because they meet the following criteria: (1) the code contains products from 1 of 10 recognized high technology fields such as electronics (which includes semiconductors) and information and communications (which includes notebook computers and cell phones), (2) these products represent leading-edge technology in that field, and (3) these products constitute a significant part of all items in the selected classification code.

Partly as a consequence of the growing movement of electronics assembly to Asia, and China in particular, in 2005, the United States trade deficit with China in the ATP information and communications group, $51.5 billion, is slightly larger than the overall ATP deficit with China, $48.4 billion, and about 25 percent of the overall goods deficit, $203.8 billion, all of which have dramatically grown in recent years.[1] Finished products—such as notebook computers and cell phones—are the largest U.S. information and communication ATP imports from China in 2005. Computer parts and accessories are the leading U.S. exports to China in this group. U.S. exports, imports, and the trade balance with China in this group are depicted in figure 15. This figure shows both the rapid growth in imports of these products from China, as well as the rising trade deficit.[2]

[1]We present narrow definitions of ATP trade statistics-- "domestic exports" and "imports for consumption" because we wish to exclude flows of goods for which the United States is simply a transshipment point. Census publishes the broad definition of ATP trade statistics—"total exports" and "general imports." Nonetheless in recent years, both narrow and broad ATP trade flows with China display similar patterns.

[2]For more information on the U.S.-China trade and investment relationship, see GAO, *China Trade: U.S. Exports, Investment and Affiliate Sales Rising, but Export Share Falling*, GAO-06-162 (Washington, D.C.: Dec. 9, 2005).

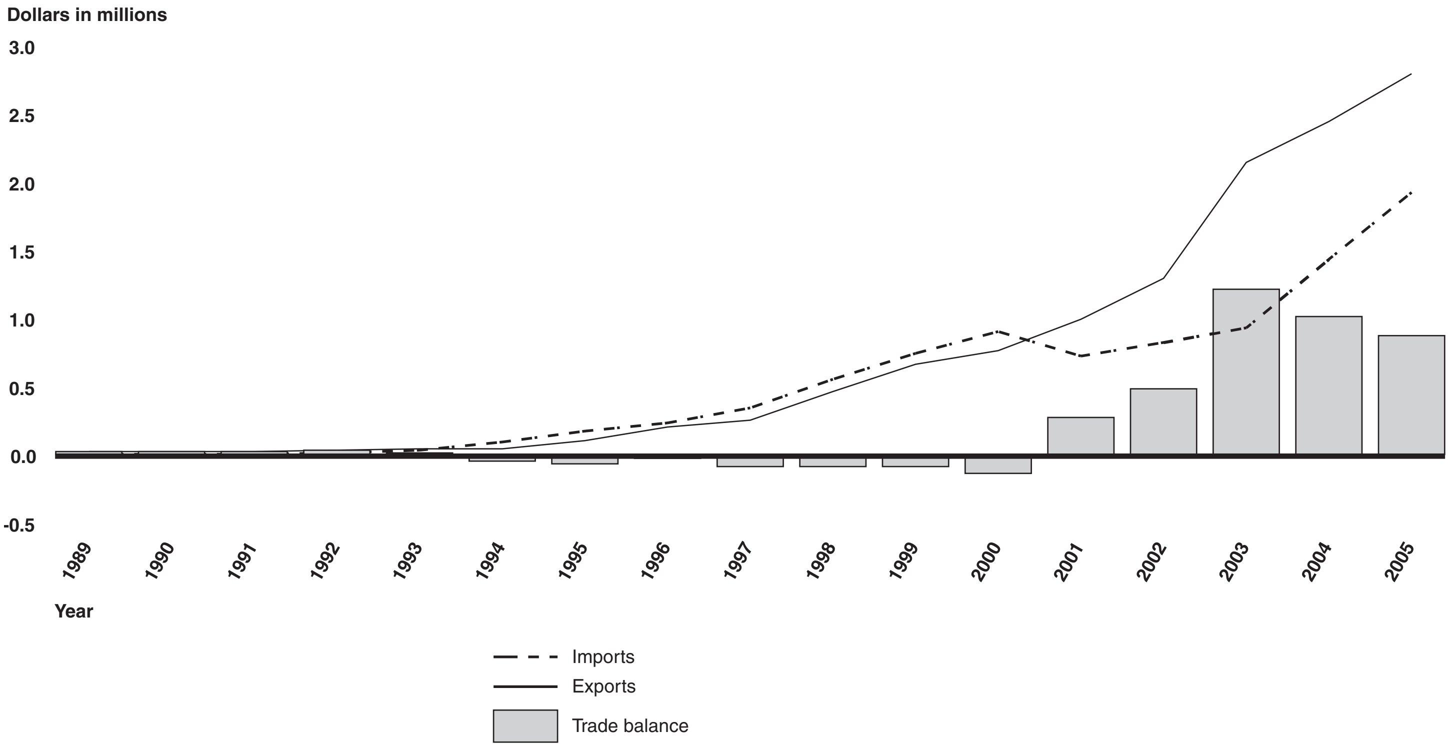
Figure 15: U.S. ATP Information and Communications Trade with China



Source: GAO analysis of Census data.

In contrast, in the ATP electronics group, beginning in 2001, the United States has a trade surplus with China, largely due to the substantial exports of semiconductor wafers and integrated circuits to China. (See fig. 16.) However, this surplus of about $1 billion in 2003 has been declining somewhat in recent years. This current trade surplus is partly a result of slower growing U.S. demand for finished integrated circuits by downstream manufacturers of consumer electronics, as discussed previously.

Figure 16: U.S. ATP Electronics Trade with China



Source: GAO analysis of Census data.

The overall ATP trade deficit with China (as well as Asia overall) is largely due to information and communications imports. However, trade statistics rarely separate out the value of imported components embodied in finished products. Therefore, some part of the value of U.S. imports of information and communications products from China is attributable to U.S. exports of chips and wafers (and other ATP components) directly to China or indirectly through other Asian countries. However, to be a leading-edge product, Census must judge the product itself to use leading-edge technology, not simply some of its components. For example, although autos have many leading-edge components such as semiconductors and integrated circuits, autos are not leading-edge products.

Comments from the Department of Commerce

THE DEPUTY SECRETARY OF COMMERCE
Washington, D.C. 20230

August 7, 2006

Mr. Loren Yager
U.S. Government Accountability Office
Director, International Affairs and Trade Issues
Washington, DC 20548

Dear Mr. Yager:

Thank you for the opportunity to review and comment on GAO's draft report, "Offshoring: U.S. Semiconductor and Software Industries Increasingly Produce in China and India" (GAO-06-423). I enclose the Department of Commerce's comments.

The Department of Commerce welcomes your findings that the United States remains one of the world's largest and most advanced producers of semiconductors and software services, despite increased global competition. We also agree that U.S. industry's ability to compete will depend on investment in research and development, an innovative academic environment, and a competitive business environment.

This report will provide Congress with a better understanding of offshoring in the semiconductor and software services industries. We look forward to the publication of your final report in September 2006.

Sincerely,

David A. Sampson

Enclosure

GAO Contact and Staff Acknowledgments

GAO Contact

Loren Yager, Director, (202) 512-4128, yagerl@gao.gov

Staff Acknowledgments

In addition to the individual named above, Virginia Hughes, Assistant Director; Bradley Hunt; Ernie Jackson; Sona Kalapura; Judith Knepper, Analyst-in-Charge; Lynn Cothern; Yesook Merrill; Berel Spivack; and Tim Wedding made major contributions to this report.

Related GAO Products

Offshoring

Offshoring in Six Human Services Programs: Offshoring Occurs in Most States, Primarily in Customer Service and Software Development. GAO-06-342. Washington, D.C.: Mar. 28, 2006.

Offshoring of Services: An Overview of the Issues. GAO-06-5. Washington, D.C.: Nov. 28, 2005.

International Trade: U.S. and India Data on Offshoring Show Significant Differences. GAO-06-116. Washington, D.C.: Oct. 27, 2005.

International Trade: Current Government Data Provide Limited Insight into Offshoring of Services. GAO-04-932.Washington, D.C.: Sept. 22, 2004.

Highlights of a GAO Forum: Workforce Challenges and Opportunities For 21st Century: Changing Labor Force Dynamics and the Role of Government Polices. GAO-04-845SP. Washington, D.C.: June 1, 2004.

China

China Trade: U.S. Exports, Investment, Affiliate Sales Rising, but Export Share Falling. GAO-06-162. Washington, D.C.: Dec. 9, 2005.

U.S.-China Trade: Opportunities to Improve U.S. Government Efforts to Ensure Open and Fair Markets., GAO-05-554T. Washington, D.C.: Apr. 14, 2005.

U.S.-China Trade: Observations on Ensuring China's Compliance with World Trade Organization Commitments. GAO-05-295T. Washington, D.C.: Feb. 4, 2005.

U.S.-China Trade: Opportunities to Improve U.S. Government Efforts to Ensure China's Compliance with World Trade Organization Commitments. GAO-05-53. Washington, D.C.: Oct. 6, 2004.

World Trade Organization: U.S. Companies' Views on China's Implementation of Its Commitments. GAO-04-508. Washington, D.C.: Mar. 24, 2004.

Export Controls: Rapid Advances in China's Semiconductor Industry Underscore Need for Fundamental U.S. Policy Review. GAO-02-620. Washington, D.C.: Apr. 19, 2002.

Semiconductors

Export Controls: System for Controlling Exports of High Performance Computing Is Ineffective. GAO-01-10. Washington, D.C.: Dec. 18, 2000.

Federal Research: SEMATECH's Technological Progress and Proposed R&D Program. RCED-92-223BR. Washington, D.C.: July 16, 1992.

Federal Research: SEMATECH's Efforts to Strengthen the U.S. Semiconductor Industry. RCED-90-236. Washington, D.C.: Sept. 13, 1990.

GAO's Mission

The Government Accountability Office, the audit, evaluation and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through GAO's Web site (www.gao.gov). Each weekday, GAO posts newly released reports, testimony, and correspondence on its Web site. To have GAO e-mail you a list of newly posted products every afternoon, go to www.gao.gov and select "Subscribe to Updates."

Order by Mail or Phone

The first copy of each printed report is free. Additional copies are $2 each. A check or money order should be made out to the Superintendent of Documents. GAO also accepts VISA and Mastercard. Orders for 100 or more copies mailed to a single address are discounted 25 percent. Orders should be sent to:

U.S. Government Accountability Office
441 G Street NW, Room LM
Washington, D.C. 20548

To order by Phone: Voice: (202) 512-6000
TDD: (202) 512-2537
Fax: (202) 512-6061

To Report Fraud, Waste, and Abuse in Federal Programs

Contact:

Web site: www.gao.gov/fraudnet/fraudnet.htm
E-mail: fraudnet@gao.gov
Automated answering system: (800) 424-5454 or (202) 512-7470

Congressional Relations

Gloria Jarmon, Managing Director, JarmonG@gao.gov (202) 512-4400
U.S. Government Accountability Office, 441 G Street NW, Room 7125
Washington, D.C. 20548

Public Affairs

Paul Anderson, Managing Director, AndersonP1@gao.gov (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, D.C. 20548

PRINTED ON RECYCLED PAPER