Overview

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Introduction

This overview of the National Science Board's *Science and Engineering Indicators 2010* brings together some major developments in international and U.S. science and technology (S&T). It is not intended to be comprehensive; the reader will find more extensive data in the body of each chapter. Major findings on particular topics appear in the Highlights sections that precede chapters 1–7.

The indicators included in *Science and Engineering Indicators 2010* derive from a variety of national, international, public, and private sources and may not be strictly comparable in a statistical sense. As noted in the text, some data are weak, and the metrics and models relating them to each other and to economic and social outcomes invite further development. Thus, the emphasis is on broad trends; individual data points and findings should be interpreted with care.

The overview focuses on the trend in the United States and many other parts of the world toward the development of more knowledge-intensive economies, in which research, its commercial exploitation, and other intellectual work play a growing role. Industry and government play key roles in these changes.

The overview examines how these S&T patterns and trends affect the position of the United States, using broadly comparable data wherever possible for the United States, the European Union (EU), Japan, China, and selected other Asian economies (the Asia-9: India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Thailand, Taiwan, and Vietnam).

The overview sketches an analytical framework for, and a broad outline of, the main S&T themes, which it then examines through the lens of various indicators such as global R&D expenditures and human resources, including researchers. It describes research outputs and their use in the form of article citations and patents. It then turns to the growth and structural shifts in international high-technology markets, trade, and relative trade positions.

The data available as of this writing do not, for the most part, cover the ongoing changes that shook the global economy beginning in 2008. The data therefore cannot accurately portray their consequences for the world's S&T enterprise. Thus, the trends discussed here may already be changing in unexpected ways. Nevertheless, major patterns and trends that have developed over the past decade or more affect, and are shaped by, the range of S&T endeavors, from basic research to production and trade of high-technology goods and knowledge-intensive services. They are the starting points from which to mark any future changes.

A Bird's Eye View of the World's Changing S&T Picture

Since the 1990s, a global wave of market liberalization has produced an interconnected world economy that has brought unprecedented levels of activity and growth, along with structural changes whose consequences are not yet fully understood. Governments in many parts of the developing world have come to view science and technology (S&T) as integral to economic growth and development, and they have set out to build more knowledge-intensive economies in which research, its commercial exploitation, and intellectual work would play a growing role.

To that end, they have taken steps to open their markets to trade and foreign investment, develop or recast their S&T infrastructures, stimulate industrial R&D, expand their higher education systems, and build indigenous R&D capabilities. This has brought a great expansion of the world's S&T activities and their shift toward developing Asia, where most of the rapid growth has occurred. Governments there have implemented a host of policies to boost S&T capabilities as a means to ensuring their economies' competitive edge.

In most broad aspects of S&T activities, the United States continues to maintain a position of leadership but has experienced a gradual erosion of its position in many specific areas. Two contributing developments are the rapid increase in a broad range of Asian S&T capabilities outside of Japan and the fruition of EU efforts to boost its relative competitiveness in R&D, innovation, and high technology.

Asia's rapid ascent as a major world S&T center—beyond Japan—is driven by developments in China and several other Asian economies (Asia-9).[1] All are seeking to boost access to and the quality of higher education and to develop world-class research and S&T infrastructures. The Asia-9 form a loosely structured supplier zone for China's high-technology manufacturing export industries that increasingly appears to include Japan. Japan, long a preeminent world S&T nation, is holding its own in research and some high-value S&T activities but is losing ground to the Asia-9 in overall high technology manufacturing and trade. India's high gross domestic product (GDP) growth contrasts with a fledgling overall S&T performance.

The EU largely holds its own in the face of these worldwide S&T shifts. Its innovation-focused policy initiatives have been supported by the creation of a shared currency and the elimination of internal trade and migration barriers. Much of the EU's high-technology trade is with other EU members. EU research performance is strong and marked by pronounced EU-supported, intra-EU collaboration. The EU is also focused on boosting the quality and international standing of its universities.

Other countries share this heightened focus on S&T as a means of economic growth. Brazil and South Africa show high S&T growth rates, but from low bases. Among the more developed nations, Russia's S&T establishment continues to struggle in both relative and absolute terms, whereas Israel, Canada, and Switzerland are examples of mature, high-performing S&T establishments.

Multinational companies (MNCs) operating in this changing environment are seeking access to developing markets, whose governments provide incentives. Modern communications and management tools support the development of globally oriented corporations that draw on far-flung, specialized global supplier networks. In turn, host governments are attaching conditions to market access and operations that, along with technology spillovers, produce new and greater indigenous S&T capabilities. Western- and Japan-based MNCs are increasingly joined in world S&T markets by newcomers headquartered in developing nations.

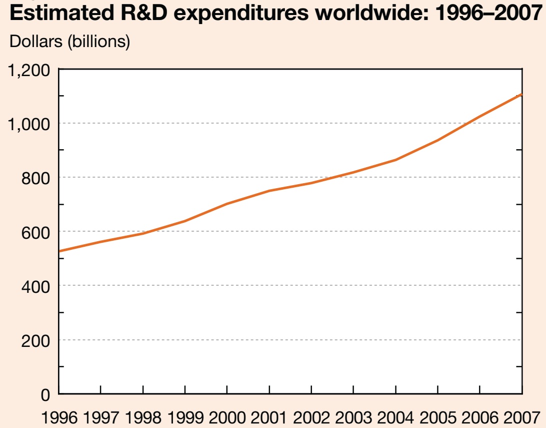
Global Expansion of Research and Development Expenditures

In a telling development, the world's R&D expenditures have been on an 11-year doubling path, growing faster than total global economic output.[2] This indicator of commitment to innovation went from an estimated $525 billion in 1996 to approximately $1.1 trillion in 2007 (figure O-1). The specific data point for each year shown in figure O-1 is an imprecise estimate, but the steady and large upward trend illustrates the rapidly growing global focus on innovation.[3]

The United States remained by far the single largest R&D-performing country. Its R&D expenditure of $369 billion in 2007 exceeded the Asian region's total of $338 billion and the EU's (EU-27) $263 billion[4] (figure O-2). The U.S. 2007 total broadly matched the combined R&D expenditures of the next four largest countries: Japan, China, Germany, and France.

If R&D expenditures are long-term investments in innovation, how much of a nation's economic activity should be devoted to them? A U.S. goal in the 1950s was to achieve an R&D investment of 1% of GDP by 1957. More recently, many governments set their sights at 3% of GDP in pursuit of developing knowledge-based economies; the EU formally embraced the 3% goal as its long-term planning target.[5]

Figure O-1
Estimated R&D expenditures worldwide: 1996–2007



SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2009/1 and previous years); United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics, http://stats.uis.unesco.org/unesco/tableviewer/document.aspx?ReportId=143&1F_Language=eng; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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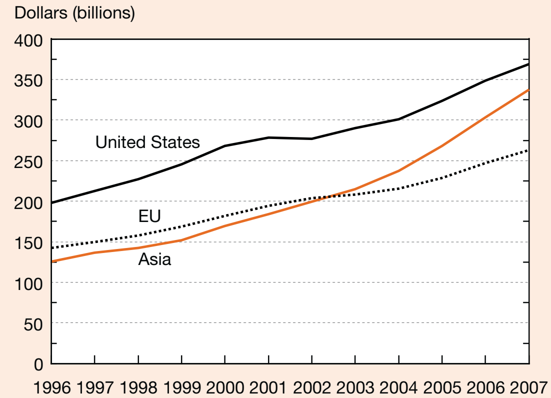
Figure O-2
R&D expenditures for United States, EU, and Asia: 1996–2007



EU = European Union

NOTE: Asia includes China, India, Japan, Malaysia, Singapore, South Korea, Taiwan, and Thailand. EU includes all 27 member states.

SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2009/1 and previous years); United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics, http://stats.uis.unesco.org/unesco/tableviewer/document.aspx?ReportId=143&1F_Language=eng; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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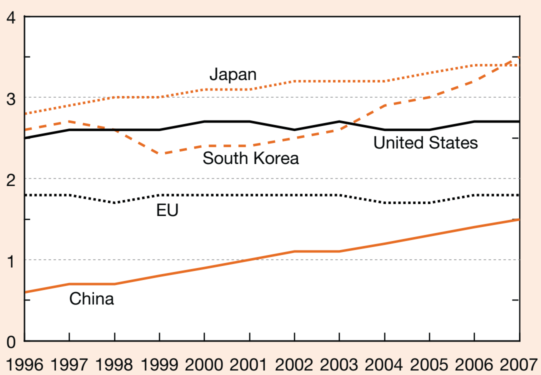
Nearly everywhere, however, decisions affecting the bulk of R&D expenditures are made by industry, thus removing achievement of such a target from direct government control. In the United States, industry funds about 67% of all R&D. For the EU, it is 55%, but with considerable range (e.g., nearly 70% for Germany and 45% for the United Kingdom). In China, Singapore, and Taiwan, industry funding ranges from 60% upward. Nevertheless, government planners monitor the R&D/GDP ratio as an indicator of innovative capacity, even as few countries reach the 3% mark.

Over the past decade, many Asian developing economies have exhibited increased R&D/GDP ratios; conversely, those in the United States and the EU have broadly held steady. Japan's R&D expenditures amounted to 3.4% of GDP in 2007; South Korea's increased steeply after the 1990s and reached 3.5% in 2007.

China's R&D/GDP ratio more than doubled, from 0.6% in 1996 to 1.5% in 2007, a period during which China's GDP grew at 12% annually—an enormous, sustained increase. The gap in China's R&D/GDP ratio relative to those of developed economies suggests that China's R&D volume can continue to grow rapidly (figure O-3).

Decade-long R&D growth rates of mature S&T countries differ dramatically from those of developing economies. Growth of R&D expenditures in the United States, the EU,

Figure O-3
R&D expenditures as share of economic output of selected countries: 1996–2007



EU = European Union; GDP = gross domestic product

NOTE: EU includes all 27 member states.

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2009/1 and previous years).

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and Japan averaged about 5%–6% annually, not adjusted for inflation. Asian growth ranged from about 9% to 10% for India, South Korea, and Taiwan to more than 20% for China. Asian R&D growth reflects rising private spending by domestic and foreign firms, as well as increased public R&D spending designed to support strategic policies that aim to raise economic competitiveness through the development of knowledge-based economies (figure O-4).

The relatively greater R&D growth rates in Asia (excluding Japan) resulted in decreases in the percentages of world R&D expenditures for the mature S&T establishments—United States, the EU, and Japan—that were substantial, especially in view of the short period and large expenditures involved. The North America region's (United States, Canada, and Mexico) share of estimated world R&D activity decreased from 40% to 35%; the EU's share declined from 31% to 28%. The Asia/Pacific region's share increased from 24% to 31% even with Japan's comparatively low growth, and the share of the rest of the world increased from 5% to 6%—still a modest level but a very large relative gain that indicates the broadly shared belief in the importance of R&D for economic development (figure O-5).

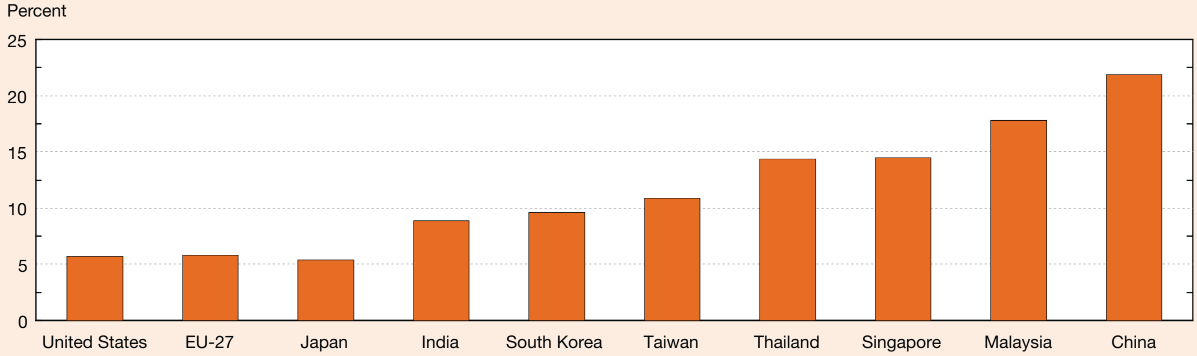
Overseas R&D by Multinational Companies

The shift toward greater R&D expenditures in Asia is also reflected in R&D flows between MNCs and their overseas affiliates in which they hold majority ownership (figure O-6).

Overseas R&D expenditures by U.S.-based MNCs ($28.5 billion in 2006) shifted toward emerging Asian markets whose combined share, excluding Japan, increased from 5% to 14% from 1995 to 2006. This change was driven by U.S. affiliates in China, South Korea, and Singapore. In 1995, about 90% of all overseas R&D by U.S.-headquartered MNCs took place in developed European economies, in Canada, and in Japan; by 2006, the combined percentage of these economies had declined to 80%.

In the United States, affiliates of foreign-headquartered MNCs spent $34.3 billion on R&D in 2006. Their R&D

Figure O-4
Average annual growth of R&D expenditures for United States, EU-27, and selected Asia-8 economies: 1996–2007



EU = European Union

SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2009/1 and previous years); United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics, http://stats.uis.unesco.org/unesco/tableviewer/document.aspx?ReportId=143&1F_Language=eng; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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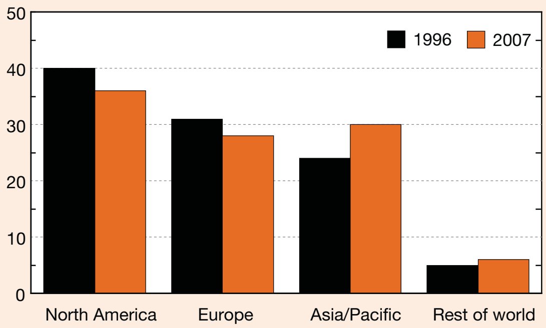
Figure O-5
Location of estimated worldwide R&D expenditures: 1996 and 2007



NOTE: Estimated total worldwide R&D expenditures were $525 billion in 1996 and $1.1 trillion in 2007.

SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2009/1 and previous years); United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics, http://stats.uis.unesco.org/unesco/TableViewer/document.aspx?ReportId=143&IF_Language=eng; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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expenditures represented about 14% of total U.S. business R&D performance, up from less than 10% in the 1980s.

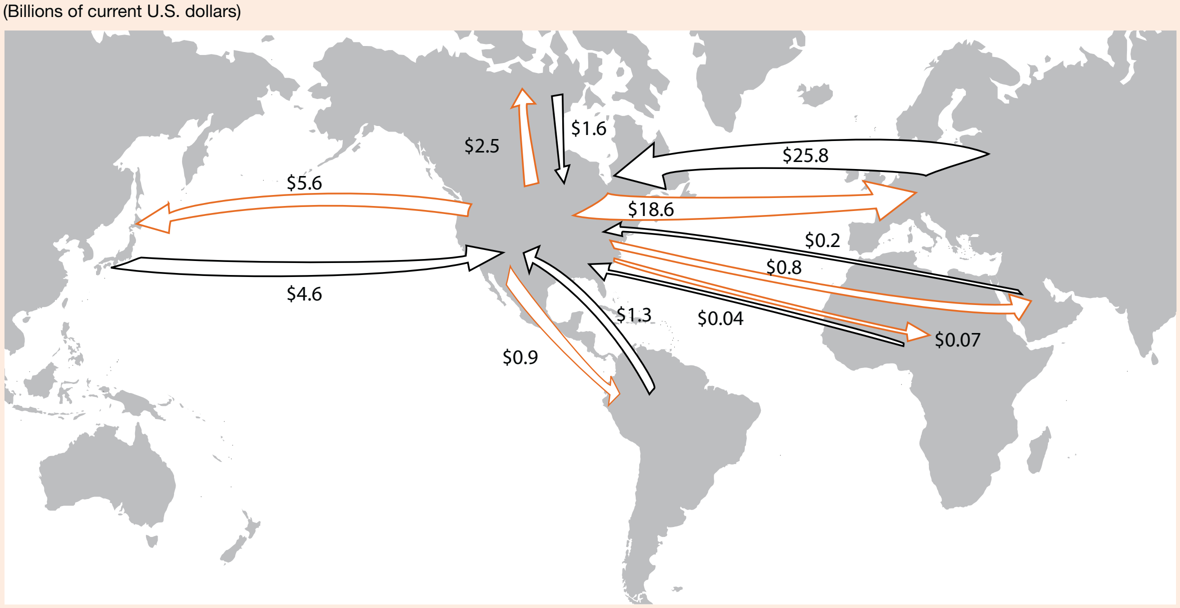
Global Higher Education and Workforce Trends

No comprehensive measures of the global S&E labor force exist, but fragmentary data indicate rapid growth in the number of individuals who pursue advanced education, especially in developing nations. In recent decades, the increasing number of new S&E degrees, including degrees in natural sciences and engineering, awarded in developing countries has diminished the advantage that mature countries had held in advanced education.[6]

Worldwide, the number of persons with a tertiary education continues to grow.[7] Estimates for 1980 and 2000, the latest available year, show an increase of about 120 million individuals, from 73 million to 194 million (figure O-7). The completion of tertiary education expanded most rapidly in developing Asian economies, where the combined shares of China, India, South Korea, the Philippines, and Thailand increased from 14% to 25% of the world's total. The number of individuals with advanced education in these Asian countries in 2000, 49 million, nearly matched the 2000 U.S. total; in 1980, these countries had accounted for less than half.

Figure O-6
R&D performed by U.S. affiliates of foreign companies in United States, by investing region, and performed by foreign affiliates of U.S. multinational companies, by host region: 2006

(Billions of current U.S. dollars)



NOTE: Preliminary estimates.

SOURCES: Bureau of Economic Analysis, Survey of Foreign Direct Investment in the United States (annual series); and Survey of U.S. Direct Investment Abroad (annual series). See appendix tables 4-32 and 4-34.

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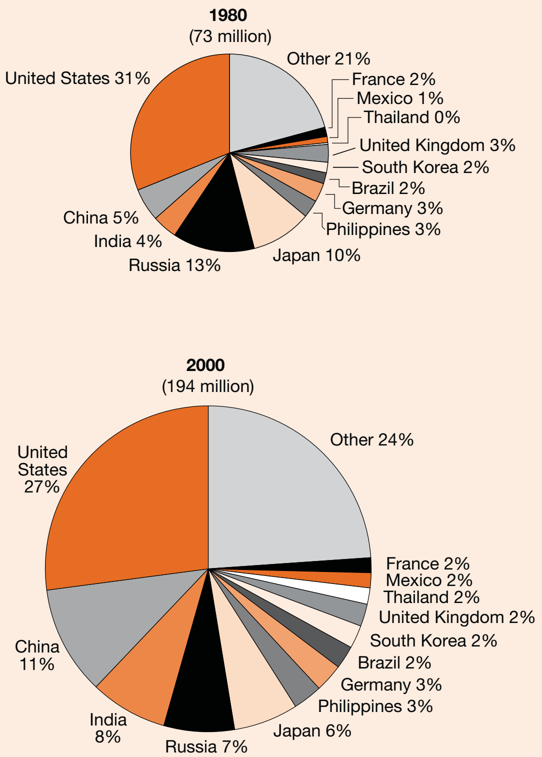
Figure O-7
Tertiary-educated population 15 years old or older, by country/economy: 1980 and 2000



NOTE: Detail may not add to total because of rounding.

SOURCE: Adapted from Barro RJ and Lee J, International data on educational attainment: Updates and implications. Center for International Development Working Paper No. 042 (2000). http://cid.harvard.edu/cidwp/042.htm, accessed 9 September 2009.

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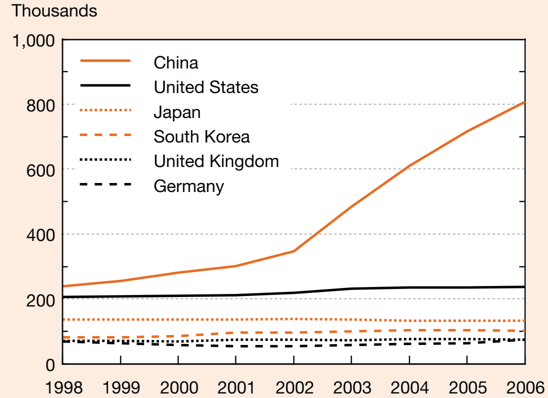
Trends in fragmentary international degree data suggest that Asian growth has continued and perhaps accelerated.

Governments in many Western countries and in Japan are concerned about lagging student interest in studying natural sciences or engineering (NS&E), fields they believe convey technical skills and knowledge that are essential for knowledge-intensive economies. In the developing world, the number of first university NS&E degrees, broadly comparable to a U.S. baccalaureate, is rising, led by large increases in China, from about 239,000 in 1998 to 807,000 in 2006. New NS&E degrees earned by Japanese and South Korean students combined in 2006 (about 235,000) approximated the number earned by U.S. students in that year, even though the U.S. population was considerably larger (300 million vs. 175 million) (figure O-8).

The expansion of NS&E degrees extends beyond first university degrees to degrees certifying completed advanced study. Since the early 1990s, the number of NS&E doctorates awarded in Japan and India has increased by more than 70%—to approximately 7,100 and 7,500, respectively. The number awarded in South Korea nearly tripled over the same period, reaching approximately 3,500. China's domestic NS&E doctorate awards have increased more than tenfold over the period, to about 21,000 in 2006, nearing the number of NS&E doctorates awarded in the United States (figure O-9).

Figure O-8
First university degrees in natural sciences and engineering, selected countries: 1998–2006



NOTE: Natural sciences include physical, biological, earth, atmospheric, ocean, agricultural, and computer sciences and mathematics.

SOURCES: China—National Bureau of Statistics of China, China Statistical Yearbook, annual series (Beijing), various years; Japan—Government of Japan, Ministry of Education, Culture, Sports, Science and Technology, Higher Education Bureau, Monbusho Survey of Education; South Korea and Germany—Organisation for Economic Co-operation and Development, Online Education Database, http://www.oecd.org/education/database/; United Kingdom—Higher Education Statistics Agency; and United States—National Center for Education Statistics, Integrated Postsecondary Education Data System, Completions Survey; and National Science Foundation, Division of Science Resources Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), http://webcaspar.nsf.gov.

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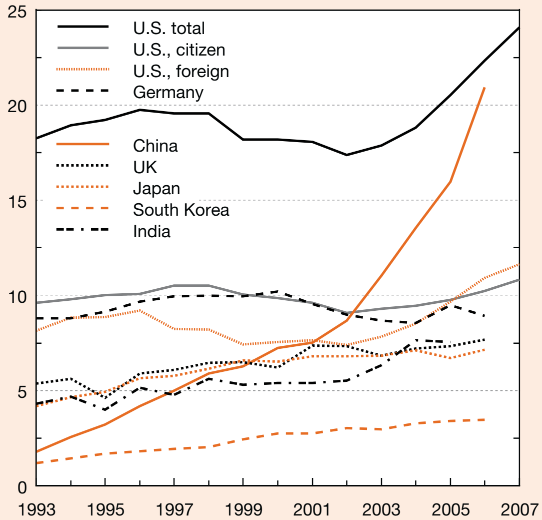
Most of the post-2002 increase in U.S. NS&E doctorate production reflects degrees awarded to temporary and permanent visa holders, who in 2007 earned about 11,600 of 22,500 U.S. NS&E doctorates.[8] Foreign nationals have earned more than half of U.S. NS&E doctorates since 2006. Half of these students are from East Asia, mostly from China (31%), India (14%), and South Korea (7%).

For engineering, the numbers are more concentrated. Since 1999, the share of U.S. engineering doctorates earned by temporary and permanent visa holders has risen from 51% to 68% in 2007. Nearly three-quarters of foreign national recipients of engineering doctorates were from East Asia or India.

Many of these individuals, especially those on temporary visas, will leave the United States after earning their doctorates, but if past trends continue, a large proportion will stay. Sixty percent of temporary visa holders who had earned a

Figure O-9
Doctoral degrees in natural sciences and engineering, selected countries: 1993–2007



UK = United Kingdom

NOTE: Natural sciences include physical, biological, earth, atmospheric, ocean, agricultural, and computer sciences and mathematics.

SOURCES: China—National Bureau of Statistics of China, China Statistical Yearbook, annual series (Beijing), various years; Japan—Government of Japan, Ministry of Education, Culture, Sports, Science and Technology, Higher Education Bureau, Monbusho Survey of Education; South Korea—Organisation for Economic Co-operation and Development (OECD), Online Education Database, http://www.oecd.org/education/ database/; United Kingdom—Higher Education Statistics Agency; Germany—Federal Statistical Agency, Prüfungen an Hochschulen, and OECD, Online Education Database, http://www.oecd.org/education/database/; and United States—National Center for Education Statistics, Integrated Postsecondary Education Data System, Completions Survey; and National Science Foundation, Division of Science Resources Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), http://webcaspar.nsf.gov.

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U.S. S&E doctorate in 1997 were gainfully employed in the United States in 2007—the highest 10-year stay rate ever observed.[9]

Expanding Global Researcher Pool

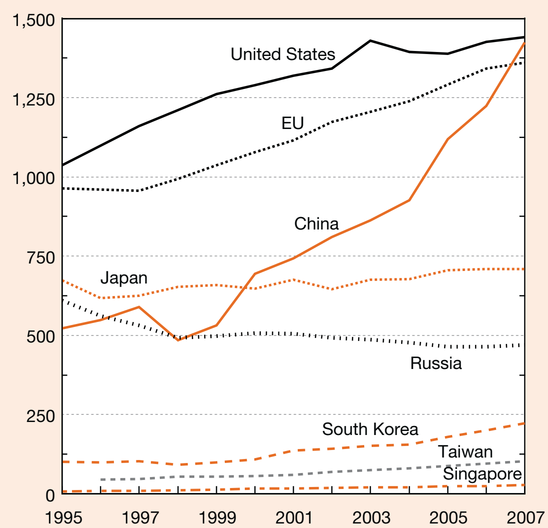
Estimates of the number of the world's researchers provide broad support for the trends and shifts suggested by the R&D and degree data discussed previously.

The estimated number of researchers grew from nearly 4 million in 1995 to about 5.7 million in 2007.[10] The United States and the 27 EU members each accounted for about 1.4 million researchers—a combined 49% of the total but below the 51% share they had held a decade earlier. China's researchers more than doubled in number, from just over half a million to more than 1.4 million, boosting its world share from 13% to 25% over the period (figure O-10).

Trends in researcher growth rates vary greatly by country/region. The United States and the EU had moderate annual growth of about 3% between 1995 and 2006. Japan's rate was below 1%. Growth in the Asian region outside Japan ranged from 7% to 11%. China, the biggest country, averaged nearly 9% growth, including a brief but sharp break in 1998–99 that reflected the rapid conversion of state-owned to privately owned enterprises as a result of the central government's policy change. Russia's researcher growth rate, which is now flat, declined over the period (figure O-11).

The contribution of multinational corporations to researcher growth in the overseas markets in which they operate is unknown. Data on overseas R&D employment of U.S.-based MNCs and their majority-owned affiliates are available only every 5 years. The latest data available show that their overseas R&D employment increased from 102,000 in 1994 to 138,000 in 2004. Over the same period, U.S. R&D employment of these MNCs increased from 625,000 to about 716,000. As a result, the overseas share of R&D employment increased from 14% to 16% (figure O-12). These data do not include researchers employed by overseas firms in which MNCs hold less than majority

Figure O-10
Researchers in selected regions/countries/ economies: 1995–2007



EU = European Union; FTE = full-time equivalent

NOTES: Researchers are full-time equivalents. Time span is 1995–2007 or closest available year. U.S. data for 2007 estimated based on 2004–06 growth rate.

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2009/1 and previous years).

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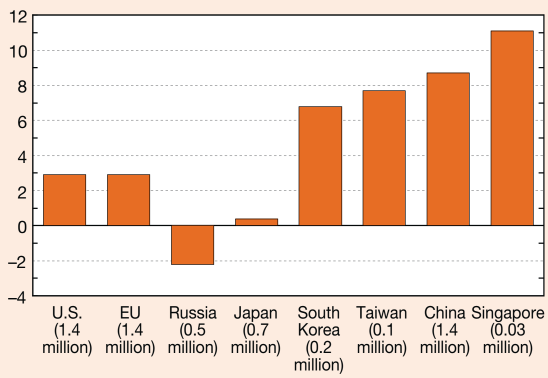
ownership or by firms that perform research under contract to MNCs.

Employment of researchers by foreign-based MNCs in other countries is unavailable, except for those working in the United States. Growth in U.S. employment of researchers working for U.S. affiliates of foreign-based MNCs has been broadly in line with overall U.S. researcher trends.

Figure O-11
Average annual growth in number of researchers in selected regions/countries/economies: 1995–2007



EU = European Union

NOTES: Researchers are full-time equivalents. Time span is 1996–2007 or closest available year. Number of researchers in 2007 or most recent year in parentheses. U.S. data for 2007 estimated based on 2004–06 growth rate. EU includes all 27 member states.

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2009/1 and previous years); and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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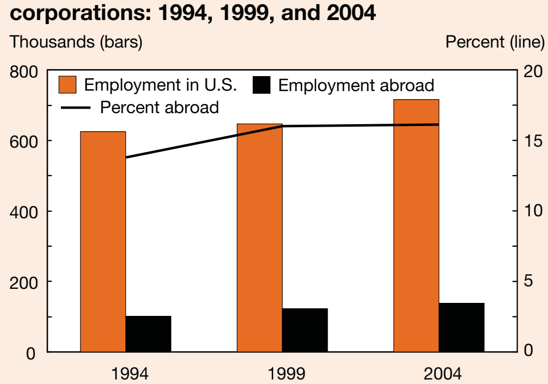
Figure O-12
R&D employment of U.S.-based multinational corporations: 1994, 1999, and 2004



NOTE: Employment abroad limited to majority-owned affiliates.

SOURCE: Bureau of Economic Analysis, International Economic Accounts, U.S. Direct Investment Abroad (2004 and previous years), http://www.bea.gov/International/index.htm.

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Research Outputs: Journal Articles and Patents

Research produces new knowledge, products, or processes. Research publications reflect contributions to knowledge, patents indicate useful inventions, and citations on patent applications to the scientific and technical literature indicate the linkage between research and practical application.

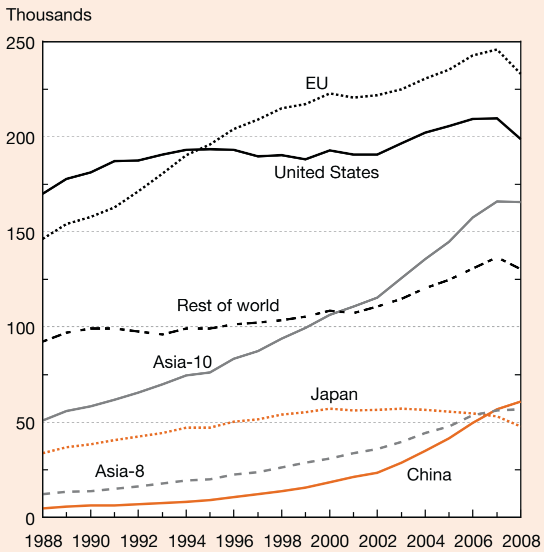
The number of research articles published in a set of international, peer-reviewed journals has grown from about 460,000 in 1988 to an estimated 760,000 in 2008.[11] The geographical distribution of the authors provides yet another indication of the size of a country's or region's research enterprise and its ability to produce research results that can pass peer review.

Researchers in the EU and the United States have long dominated world article production, but their combined world share of published articles decreased steadily from 69% in 1995 to 59% in 2008 as Asia's output increased. In little more than a decade, Asia's world article share expanded from 14% to 23%. The increase principally reflected China's output volume, which expanded by about 14% annually over the period. In 2008, China produced about 8% of world article output, up from 1% in 1988. By 2007, China's publication volume exceeded Japan's, moving it into 2nd place behind the United States—a distant 2nd place, but up from 14th place in 1995. In contrast, India's output of scientific and technical articles stagnated through the late 1990s before beginning to increase, and India's ranking hardly moved, changing from 12th place in 1995 to 11th place in 2008 (figure O-13).

The distribution of a country's research publications across different fields broadly reflects its research priorities. In 2007, more than half of the articles published by U.S. researchers reported on work in the biomedical and other life sciences, whereas scientists in Asia and some major European countries published a preponderance of articles in the physical sciences[12] and engineering (figure O-14). Priority shifts not evident in figure O-14 include China's growing focus on chemistry R&D (related articles increased as a share of China's S&E articles from 13% in 1988 to 24% in 2008) and declining share of other physical sciences articles (from 39% to 28%) as well as South Korea's shift toward greater output in biological and medical sciences (from a combined 17% to 38%). These changes in research portfolios reflect government policy choices: China is building up its chemicals industry; South Korea is trying to develop a reputation in health sciences.

Worldwide, the number of engineering research articles increased substantially faster over the past 20 years than total S&E article production, particularly in Asia, where the growth rate (7.8%) in engineering article output exceeded that of total S&E article output (6.1%). Growth in the United States and Japan averaged less than 2%; in the EU, about 4.4%. China's engineering article output grew by close to 16% annually, and the Asia-8 economies expanded their combined output by 10% a year.

Figure O-13
S&E journal articles produced by selected regions/ countries: 1988–2008



EU = European Union

NOTES: See glossary for countries included in Asia-8 and Asia-10. EU includes all 27 member states. Articles classified by year of publication and assigned to region/country on basis of authors' institutional address(es). For articles with collaborating institutions from multiple countries/ economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Counts for 2008 are incomplete.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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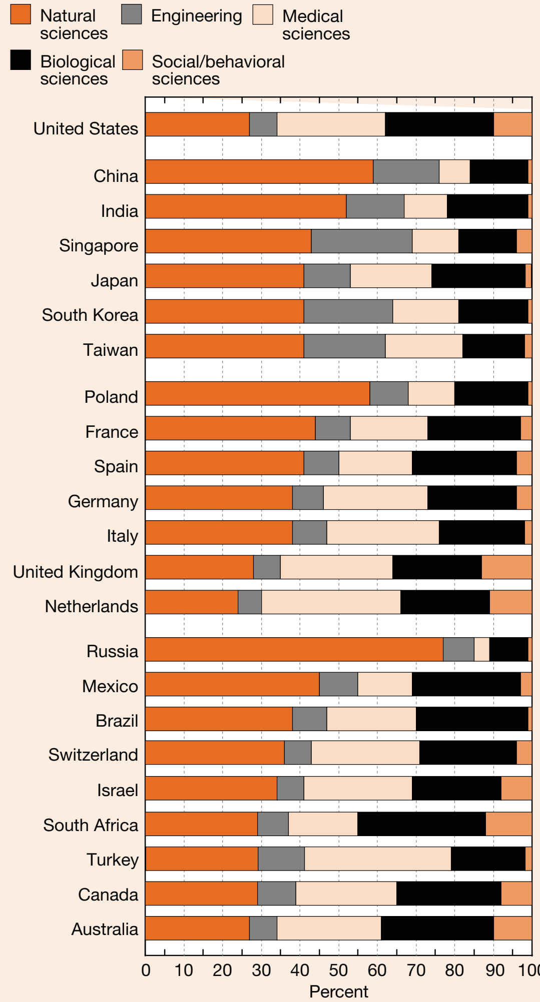
Consequently, the production of engineering research articles has shifted away from established S&T nations. In 1988, the U.S. share of engineering articles was 36%; by 2008, it was 20%. Japan's share declined from 12% to 7% during the same period. Only the EU managed to maintain its share at 28%. Asia's share, excluding Japan, increased from 7% to 30%, with China producing nearly half (14%) of these articles by 2008 (figure O-15).

This strong and rapidly growing preponderance of engineering articles produced in developing Asian economies (figure O-16) is consistent with the region's emphasis on developing high-technology manufacturing capabilities. The Asia-10 region produced more engineering articles than the United States starting in 1999 and overtook the EU in 2003. In 2005, China overtook Japan in engineering article output and moved from ninth place in 1988 to second place. India's relative strength in engineering allowed it to move from seventh place to fifth place in the past 10 years.

Figure O-14
Field shares of research articles for selected countries/economies: 2007



NOTE: Natural sciences include astronomy, chemistry, physics, geosciences, mathematics, and computer sciences.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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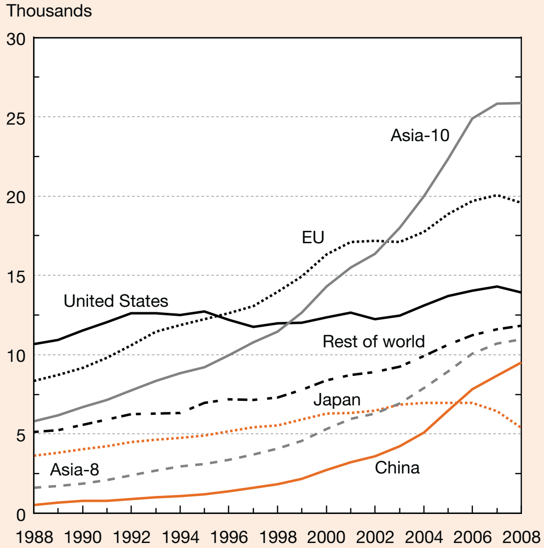
Expanding International Research Collaborations

Collaborative research is becoming the norm, as indicated by the increasing coauthorship of journal articles. Articles with authors in two or more countries have increased in number faster than any other segment of the S&E literature, indicating growing collaboration across national boundaries. In 1988, only 8% of the world's S&E articles

Figure O-15
Engineering journal articles produced by selected regions/countries: 1998–2008



EU = European Union

NOTES: See glossary for countries included in Asia-8 and Asia-10. Articles classified by year of publication and assigned to region/country on basis of authors' institutional address(es). For articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Articles counts are 2-year moving average. Counts for 2008 are incomplete.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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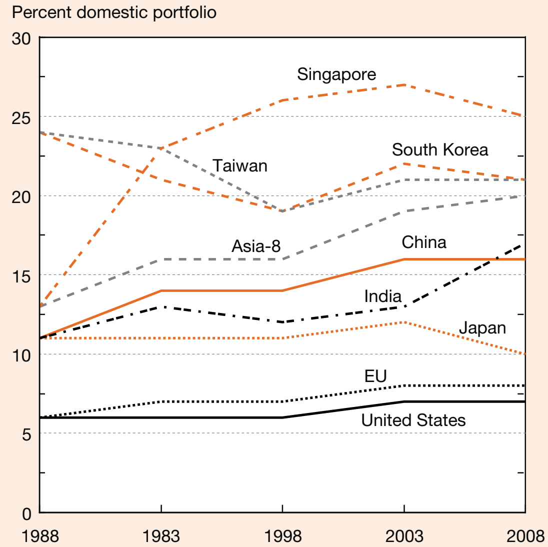
Figure O-16
Engineering article share of total S&E article output for selected regions/countries/economies: 1988–2008



EU = European Union

NOTES: See glossary for countries included in Asia-8. EU includes all 27 member states. Articles classified by year of publication and assigned to region/country on basis of authors' institutional address(es). For articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit based on proportion of its participating institutions. Counts for 2008 are incomplete.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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had international coauthors; by 2007, this share had grown to 22%.

The United States rate of international collaboration is similar to that of Japan and China but lower than that of the EU, where explicit EU policies coupled with incentives stimulate international, and specifically intra-EU, collaboration (figure O-17). As a result of the large volume of total U.S. article output, however, U.S.-based authors appeared on 43% of the world's internationally coauthored articles in 2008.

An index of international collaboration corrects for the effects of unequal size of countries' research establishments.[13] It summarizes regional and country coauthorship patterns, with values above "1" indicating higher-than-expected, and values below 1 indicating lower-than-expected, collaborations.

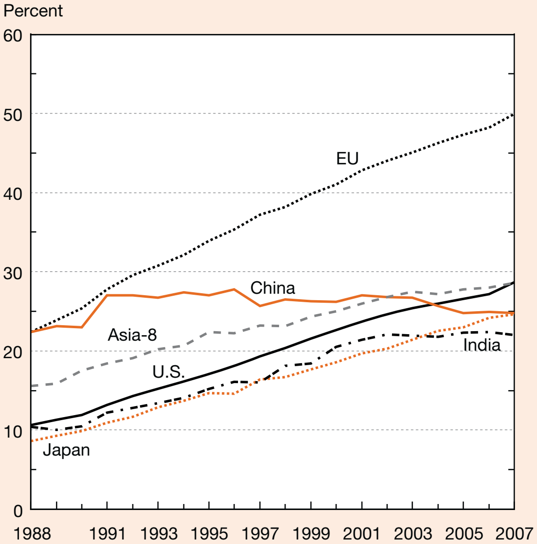
U.S. international collaborations measured by this bilateral index were widespread, were generally lower than expected, and remained mostly steady over the past decade (1998–2008). EU collaborations were equally widespread, were generally lower than expected for its large members, and increased measurably over the period, quite likely in response to explicit EU policies. Unlike the index values for established scientific nations, Asia's index values were substantially higher than expected.

In 2008, U.S. research collaborations were especially strong with Canada and Mexico in North America (1.18 and 1.03), with Israel (1.25), and with South Korea and Taiwan in Asia (1.23). U.S. collaborations with China, Japan, and India were above the U.S. average.

EU policies to increase intra-European research integration appear to be having their desired effect, as intra-EU collaboration index values increased substantially over the period, most of them above unity.

Intraregional collaborations are prevalent in Asia, where they have developed even without the integrating framework provided by the EU. Over the 10-year period, high levels of collaboration were evident between China and Japan, South Korea, Singapore, and Taiwan, whereas the rate of collaboration between China and India diminished noticeably. India, in turn, collaborated more with Japan, South Korea, Singapore, and Taiwan. The underlying index values

Figure O-17
International coauthorship of S&E articles, by region/country: 1988–2007



EU = European Union

NOTES: See glossary for countries included in Asia-8. EU includes all 27 member states. Articles classified by year that they entered the database and assigned to region/country on basis of authors' institutional address(es). Each collaborating country or sector credited one count.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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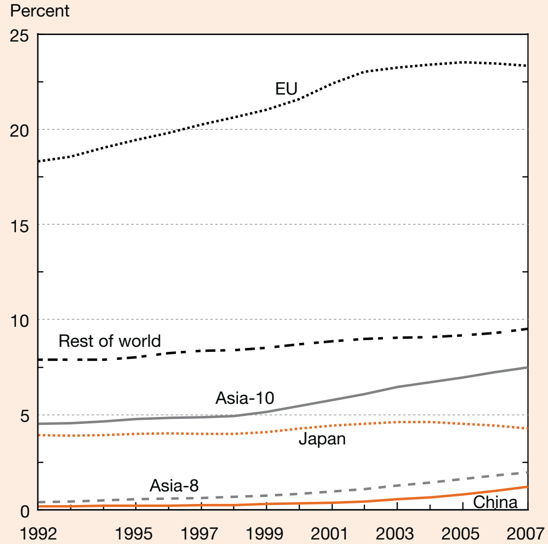
Figure O-18
Citations in U.S. S&E articles to non-U.S. publications: 1992–2007



EU = European Union

NOTES: See glossary for countries included in Asia-8 and Asia-10. EU includes all 27 member states. Articles classified by year that they entered the database and assigned to region/country on basis of authors' institutional address(es). For articles with collaborating institutions from multiple countries/ economies, each country/ economy receives fractional credit on basis of proportion of its participating institutions.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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suggest the genesis of an intra-Asian zone of scientific collaboration that has a counterpart in knowledge- and technology-intensive economic activities.

New Research Patterns Reflected in World's Citations Base

Citations to the work of others in the literature are a broad indicator of the usefulness of this work in ongoing research.[14] Citations to nondomestic articles can indicate the existence of useful work being done elsewhere.

Citations in U.S. articles (henceforth, U.S. citations) to the domestic literature dropped steadily since 1992 from 69% to 60% in 2007, attesting to the growth of relevant work elsewhere. Figure O-18 shows the regional breakdown of nondomestic citations relative to total U.S. citations.

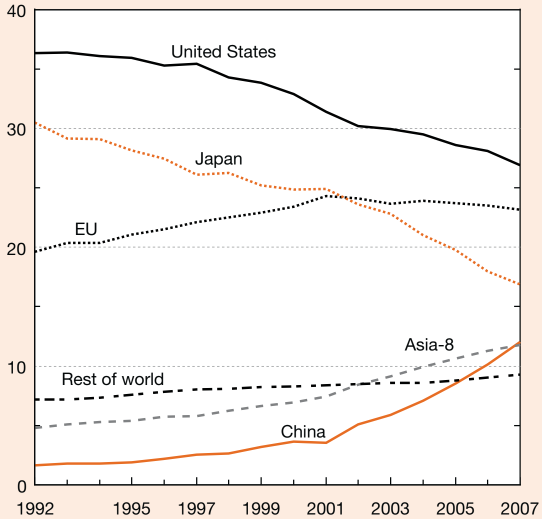
Most U.S. citations to the nondomestic literature referenced EU publications. In 2007, 23% of total U.S. citations were to EU work, up from about 18% in 1992 but flat in recent years. Over the same period, the Japanese share gradually declined. Slowly rising citation shares to work done in the Asia-8 group remained at a low level, partly because of the overall low level of their publications output, but probably also because of language, cultural barriers, and research quality.

EU citation patterns have undergone similar changes, with citations to the U.S. literature dropping from 36% to 28% over the 1992–2007 period. Total citations to Asian articles increased modestly from 5% to 8%, whereas citations to the rest of the world increased from 13% to 18%.

Major changes are evident in the Asia-10 group, whose internal citations increased from 37% to 41% of the Asia-10 total over the 1992–2007 period. Within this group, Japan's share dropped steeply from 31% to 17%, whereas China's share increased from 2% to 12% and the Asia-8's share increased from 5% to 12%. The EU share slowly increased, whereas the U.S. share declined from 36% to 27% (figure O-19).

The sheer number of citations by Chinese authors is rising steeply, but in a relative sense, Chinese authors are increasingly citing domestic articles and those by researchers in the Asia-8 group but less frequently the work of U.S. scientists. Thus, although the number of citations to U.S. articles increased from about 6,000 in 1992 to approximately

Figure O-19
Citations in Asia-10 S&E articles, by cited region/country: 1992–2007



EU = European Union

NOTES: See glossary for countries included in Asia-8 and Asia-10. EU includes all 27 member states. Articles classified by year that they entered the database and assigned to region/country on basis of authors' institutional address(es). For articles with collaborating institutions from multiple countries/ economies, each country/economy receives fractional credit on basis of proportion of its participating institutions.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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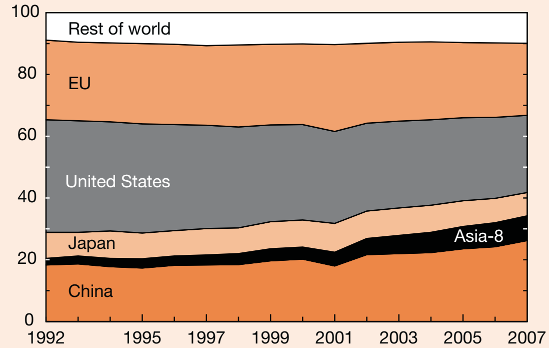
Figure O-20
Citations in China S&E articles, by cited region/country: 1992–2007



EU = European Union

NOTES: See glossary for countries included in Asia-8 and Asia-10. EU includes all 27 member states. Articles classified by year that they entered the database and assigned to region/country on basis of authors' institutional address(es). For articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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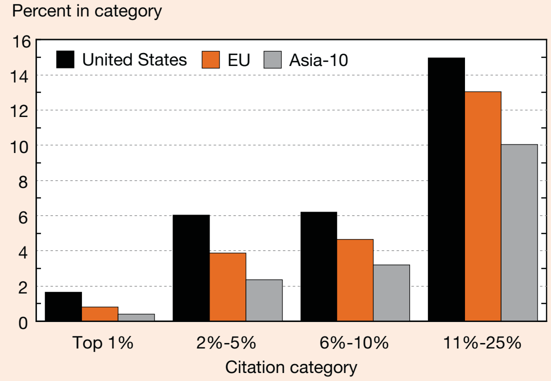
82,000 in 2007, the U.S. share contracted from 36% to 25%. Japan's share of citations in the Chinese literature has basically remained unchanged since the early 1990s; the same holds for the EU (figure O-20).

Even as global production and citation patterns have shifted, the relative quality distribution of worldwide articles, as measured by citations, has changed little. In 2007, the United States had consistently higher proportions of its articles in the most highly cited categories than the EU or the Asia-10 (figure O-21). This broad pattern held for the entire 1998–2007 period and for all major S&E fields.

Figure O-21
Share of region's/country's papers among world's most cited S&E articles: 2007



EU = European Union

NOTES: See glossary for countries included in Asia-10. EU includes all 27 member states.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Inventive Activity Shown by Patents

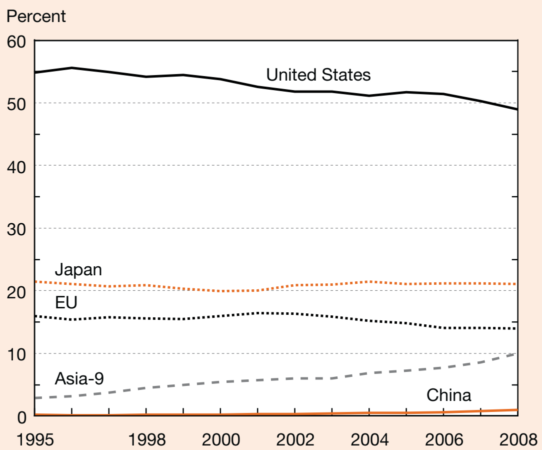
Patents are an indicator of inventive activity. By issuing patents that allow the patent owner to demand payment for their use, governments protect inventions that are new, not obvious, and useful. The U.S. Patent and Trademark Office (USPTO) grants patents to inventors from all over the world, and because of the sheer volume of U.S. patents and the importance of the U.S. market, they are a useful indicator of trends in the geographic location of inventive activity.

About half (49%) of the patents granted by the USPTO went to U.S.-based inventors in 2008, down from 55% in 1995 and somewhat below the U.S. share of applications.[15] Japan's share has been a steady 20%–22% over the period, above its share of applications; the EU members received 14%–16%. The Asia-9's share increased from 3% to 10% over the period, mostly on the strength of South Korea and Taiwan. China's share remained in the 1% range in all major technology areas. Indigenous inventive activity, a focus of government policy, appears elusive, at least as indicated by patents filed in a major Western market (figure O-22).

Patents on inventions for which protection is sought in the United States, the EU, and Japan require substantial resources for obtaining and maintaining them. This suggests that their owners consider them to be valuable. These patents are herein treated as an indicator of the distribution of high-value patenting around the world.

Just over 30% of high-value patents had U.S. inventors in 2006, down somewhat from 34% in 1997.[16] The EU's share declined somewhat more, to 29% in 2006, followed closely by Japan. The Asia-9's increasing share largely reflects patents with Korean inventors. As with U.S. patents, Chinese inventors appeared on only 1% of these high-value patents (figure O-23).

Figure O-22
Share of U.S. patent grants for selected regions/ countries: 1995–2008



EU = European Union

NOTES: See glossary for countries included in Asia-9. China includes Hong Kong. EU includes all 27 member states.

SOURCE: U.S. Patent and Trademark Office, Number of Utility Patent Applications Filed in the United States, by Country of Origin, Calendar Years 1965 to Present, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/appl_yr.htm; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Fast-Rising Global Output of Knowledge- and Technology-Intensive Firms

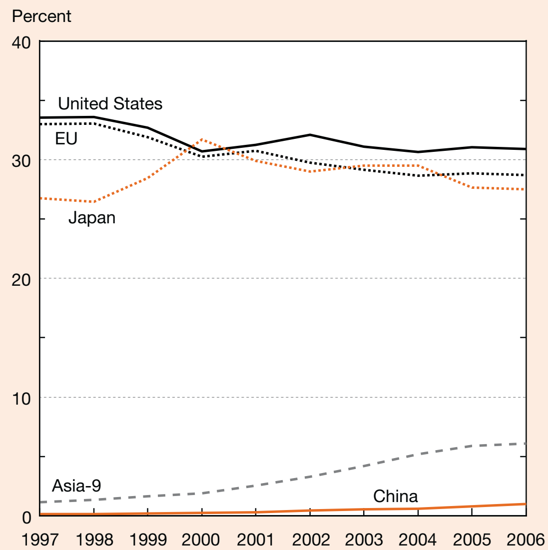
Governments in many parts of the world are acting on the conviction that knowledge- and technology-intensive economies create well-paying jobs, contribute high-value output, and ensure economic competitiveness. In response to changing opportunities, knowledge-intensive (KI) services industries and high-technology (HT) manufacturing industries have grown more rapidly than other segments of economic activity[17] (figure O-24).

In 2007, these knowledge- and technology-intensive (KTI) industries combined contributed just under $16 trillion to global economic output—about 30% of world GDP (figure O-25).

Initially these industries were the province of developed nations, but they have grown rapidly in developing markets. The global value-added volume for the largest aggregate—commercial knowledge-intensive services—increased from $4.5 trillion in 1995 to $9.5 trillion in 2007 (figure O-26).

The United States, with $3.3 trillion in 2007, produced the largest value-added output of these industries, which include business services, financial services, and communications.

Figure O-23
Share of high-value patents, for selected regions/ countries: 1997–2006



EU = European Union

NOTES: High-value patents are registered in three markets: the United States, the EU, and Japan. See glossary for countries included in Asia-9. China includes Hong Kong. EU includes all 27 member states.

SOURCE: Organisation for Economic Co-operation and Development (OECD), OECD.StatExtracts, patent statistics, http://stats.oecd.org/index.aspx; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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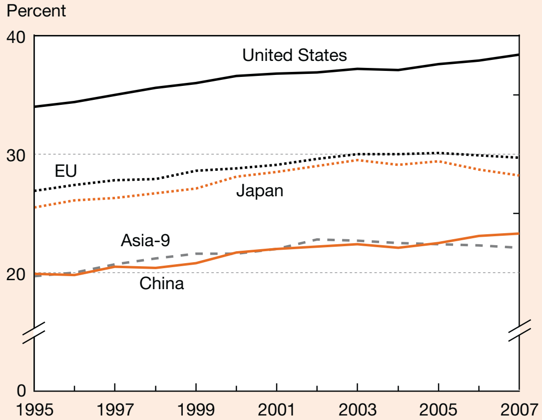
Figure O-24
Value added of knowledge-intensive and high-technology industries as share of region's/country's GDP: 1995–2007



EU = European Union; GDP = gross domestic product

NOTE: Knowledge intensive services and high technology manufacturing industries as defined by Organisation for Economic Co-operation and Development. See glossary for countries included in Asia-9. China includes Hong Kong. EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

SOURCE: IHS Global Insight, World Industry Service database, special tabulations.

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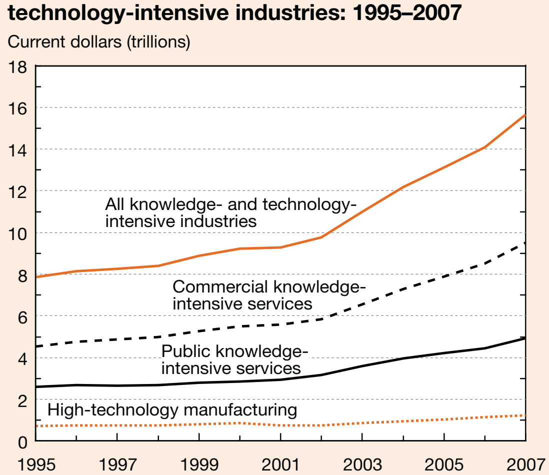
Figure O-25
Global value added of knowledge- and technology-intensive industries: 1995–2007



NOTES: Industries defined by Organisation for Economic Co-operation and Development. See glossary for definitions of knowledge-intensive services and high-technology manufacturing.

SOURCE: IHS Global Insight, World Industry Service database, special tabulations.

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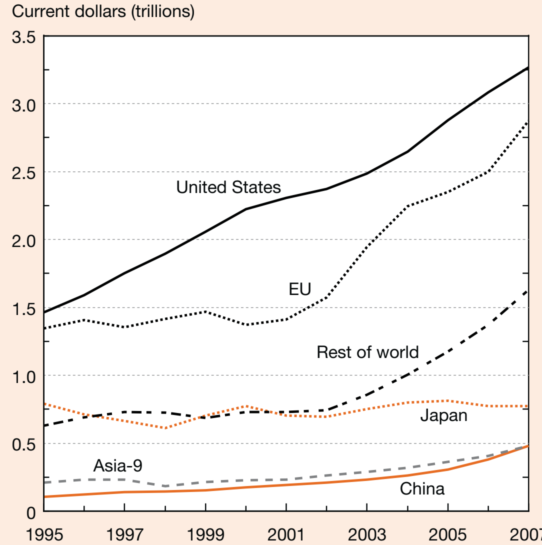
Figure O-26
Value added of commercial knowledge-intensive services, by selected region/country: 1995–2007



EU = European Union

NOTES: Industries defined by Organisation for Economic Co-operation and Development. See glossary for definitions of knowledge-intensive services and Asia-9. China includes Hong Kong. EU includes all 27 member states.

SOURCE: IHS Global Insight, World Industry Service database, special tabulations.

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The United States was followed by the EU with $2.9 trillion. World shares in these industries fluctuated for the United States and the EU, but by 2007 had settled near their 1995 levels. Increased production by China and the Asia-9 expanded their value-added output of commercial KI services, but at about half a trillion dollars each, their world market shares remained just below 5%. Flat output growth in Japan caused its market share to decline by more than half, to 8%.

The same pattern is evident in the individual KI service sectors: fluctuations in the U.S. and EU shares, steep declines for Japan's shares, and modest to rapid growth from low bases for China and the Asia-9, leading to modest increases in their world shares.

Relative to these KI trends, high-technology manufacturing shows a much stronger world position for the developing Asian economies and much steeper decline for Japan. The Asia-9 output was about 10% of the value-added world total over the 1995–2007 period, while China's share increased from 3% to 14%. Japan's share dropped from 27% to 11%. The U.S. and EU shares both showed modest upward movement.

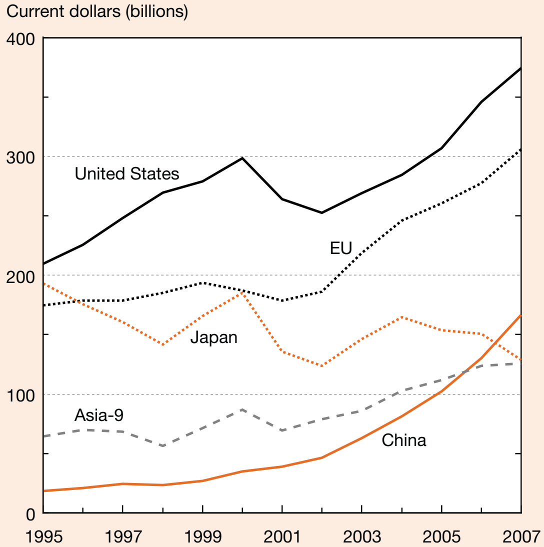
The five HT industries are, in decreasing order of the $1.2 trillion 2007 global value-added total: communications and semiconductors ($445 billion), pharmaceuticals ($319 billion), scientific instruments ($189 billion), aerospace ($153 billion), and computers and office machinery ($114 billion). The aggregate distribution by country/economy is shown in figure O-27.

The United States ranked first with 31% of the total, followed by the EU's 25% share. The United States was the world leader in communications and semiconductors (29%), pharmaceuticals (32%), and aerospace (52%), and ranked behind the EU in scientific instruments (19% vs. 44%).

However, in computers, the United States (25%), the EU (15%), and Japan (5%) all ranked well behind China (39%). This category saw a particularly rapid shift in relative world value-added positions (figure O-28).

These data obscure a larger dynamic, discussed briefly below: the development of a high-technology assembly zone in the Asia region, arrayed largely around China. It is likely that part of China's rapid growth of value-added in computer manufacturing reflects the large-scale movement of Taiwanese manufacturing facilities to, and subsequent export of computer products from, China. Nevertheless, these data highlight the growing concentration of the world's computer and office machinery manufacturing in Asia.

Figure O-27
Value added of high-technology manufacturing industries, by selected region/country: 1995–2007



EU = European Union

NOTES: Industries defined by Organisation for Economic Co-operation and Development. See glossary for definitions of high-technology manufacturing and Asia-9. China includes Hong Kong. EU includes all 27 member states.

SOURCE: IHS Global Insight, World Industry Service database, special tabulations.

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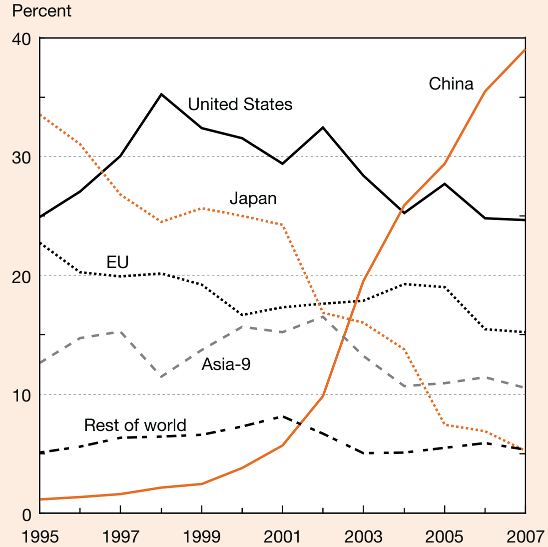
Booming Global High-Technology Exports Rearranging World Trade Patterns

The total export volume of high-technology products increased faster than gross production and pushed exports close to 60% of production in 2007, up from 37% in 1995 (figure O-29). This increase reflects the broadened international base of high-technology manufacturing, the expansion of multinational firms' overseas production, and a shift in the nature of production to increasingly specialized and geographically dispersed suppliers. The global economic slowdown is mirrored in the greater decline of exports than production and the downturn in the 2008 export share.

The global expansion of high-technology trade has made China the largest single high-technology exporter and has changed the relative positions of the developed and developing countries. China's share of world high-technology exports increased from 6% in 1995 to 20% in 2008, while the Asia-9 maintained a 26%–29% share (figure O-30). Japan's export share eroded from 18% to 8%, the U.S. share dropped from 21% to 14%, and the EU maintained a 16%–18% share.[18]

Figure O-28
Global value added market shares of computer and office machinery manufacturing, by region/country: 1995–2007



EU = European Union

NOTES: Asia-9 includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. China includes Hong Kong. EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

SOURCE: IHS Global Insight, World Industry Service database, special tabulations.

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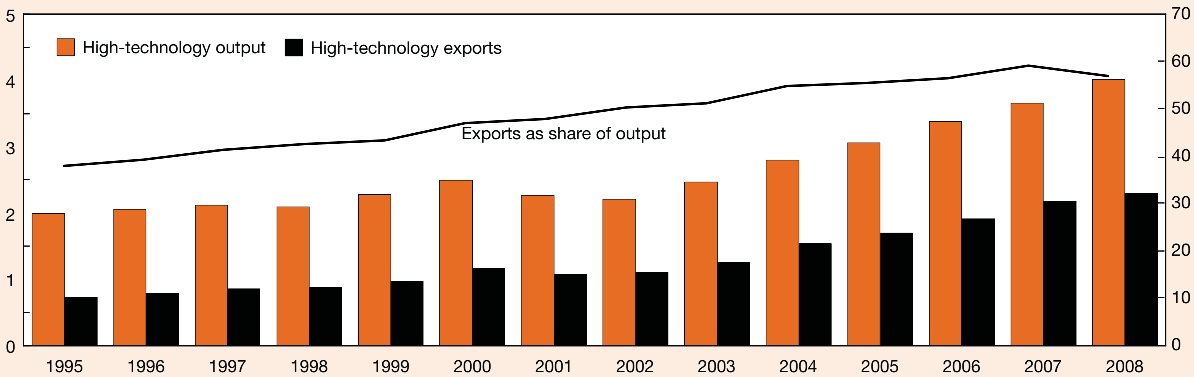
The drop in the U.S. share was driven by below-average U.S. export growth in computers and information and communications (ICT) products, contrasting with China's nearly twelvefold expansion (figures O-30 and O-31). Since 1995, China and the Asia-9 have moved from a combined 42% of ICT product exports to 64% of the world's total, and almost 70% of computers alone.

Figure O-29
Global high-technology exports as share of production: 1995–2008



NOTE: Excludes intra-European Union trade.

SOURCE: IHS Global Insight, World Industry Service and World Trade Service databases, special tabulations.

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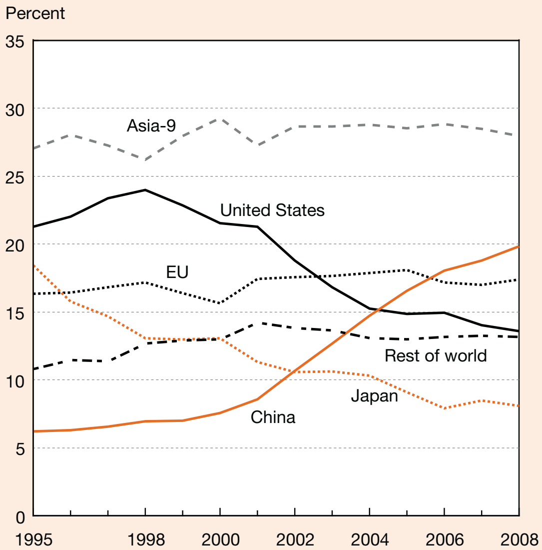
Figure O-30
Share of global high-technology exports, by region/country: 1995–2008



EU = European Union

NOTES: Excludes intra-EU trade. See glossary for countries included in Asia-9. China includes Hong Kong. EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

SOURCES: IHS Global Insight, World Trade Service database, special tabulations.

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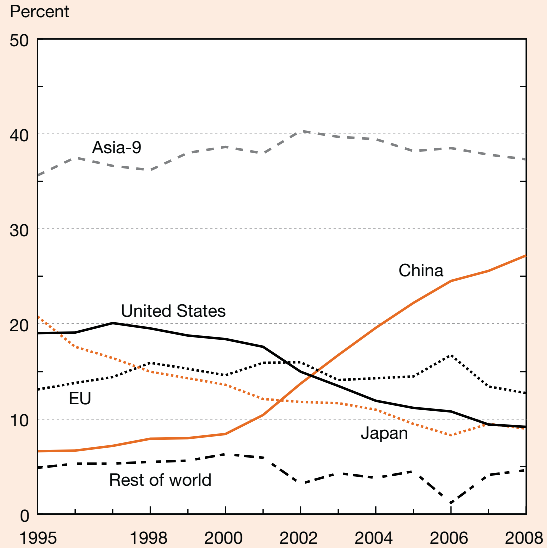
Figure O-31
Global export shares in information and communications technology products, by region/country: 1995–2008



EU = European Union

NOTE: Includes computers and communications and semiconductors. See glossary for countries included in Asia-9. China includes Hong Kong. China includes Hong Kong. EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

SOURCE: IHS Global Insight, World Trade Service database, special tabulations.

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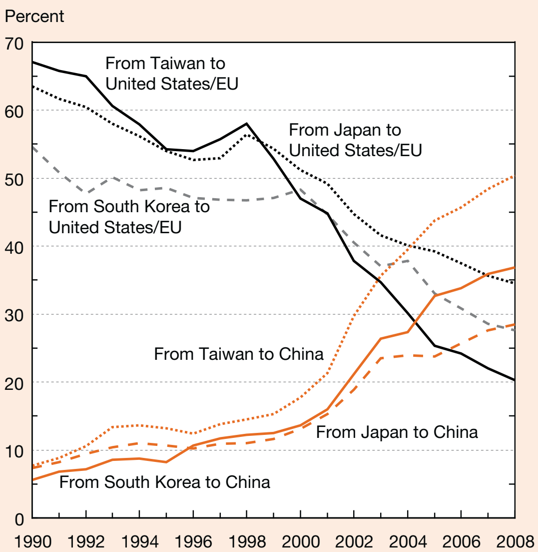
An Asian high-technology supplier zone appears to be developing that is largely arrayed around China. The shift in output of high-technology goods toward developing Asian economies has been accompanied by the growth of intraregional supplier relationships that provide intermediate goods, many for further assembly and eventual export. Chinese high-technology exports to the United States increased from $28 billion in 2000 to $112 billion 8 years later, when the U.S. recession dampened the pace of increase. Chinese exports to the EU increased at a slightly faster pace over the period (figures O-32 and O-33).

Big Shifts in World Trade Positions in High-Technology Products

In the high-technology goods trade, the United States had small trade surpluses during the mid- to late 1990s; these turned into a widening deficit after 1998 that has fluctuated at about $80 billion since 2005[19] (figure O-34). The U.S. trade deficit in ICT goods—communications and semiconductors and computers—is larger than that. It reached a record $126 billion in 2007 before contracting marginally to $119 billion in 2008, reflecting recession-induced lowered imports.

Figure O-32
Selected Asian countries'/economies' share of high-technology exports to United States/EU and China: 1990–2008



EU = European Union

NOTES: China includes Hong Kong. EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

SOURCE: IHS Global Insight, World Trade Service database, special tabulations.

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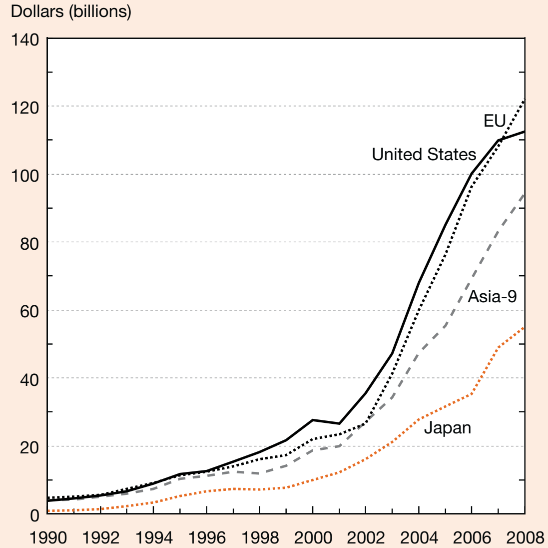
Figure O-33
China's high-technology exports to selected regions/countries: 1990–2008



EU = European Union

NOTES: See glossary for countries included in Asia-9. EU includes all 27 member states.

SOURCE: IHS Global Insight, World Trade Service database, special tabulations.

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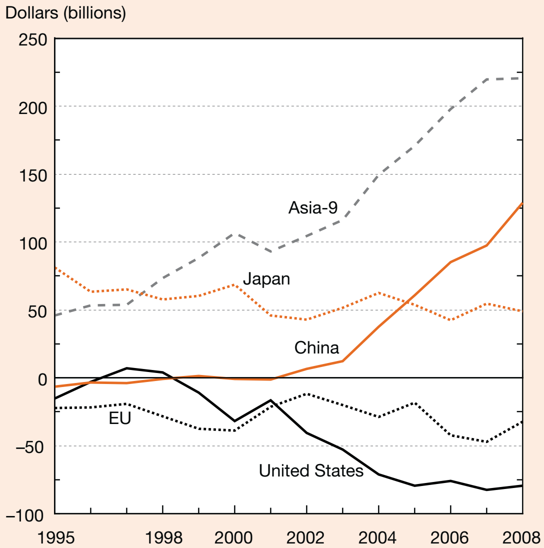
ICT goods have been the major driver behind the overall U.S. high-technology trade deficit. The broad shift in the location of production of these goods to Asia coincided with growing U.S. demand, which in turn stimulated growing imports. Pharmaceuticals contributed a further $21 billion to the 2008 deficit. Aerospace and scientific instruments were in surplus, at $50 billion and $9 billion, respectively.

The EU had a relatively stable 1995–2008 trade deficit for all high-technology classes combined, smaller than that of the United States. However, its ICT deficit was almost identical to that of the U.S., reflecting the same dynamic of rising domestic demand and relocated production. The EU's aerospace, pharmaceuticals, and scientific instruments trade balances were in surplus.

China and the Asia-9 had substantial 2008 high-technology trade surpluses of $129 billion and $221 billion, respectively. Both showed strong increases after 2002. Japan had a surplus that fluctuated at about $50 billion for most of the period, despite its loss of market share in the production of high-technology industries.

Figure O-34
Trade balance in high-technology goods for selected regions/countries: 1995–2008



EU = European Union

NOTES: See glossary for countries included in Asia-9. China includes Hong Kong. EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

SOURCE: IHS Global Insight, World Trade Service database, special tabulations.

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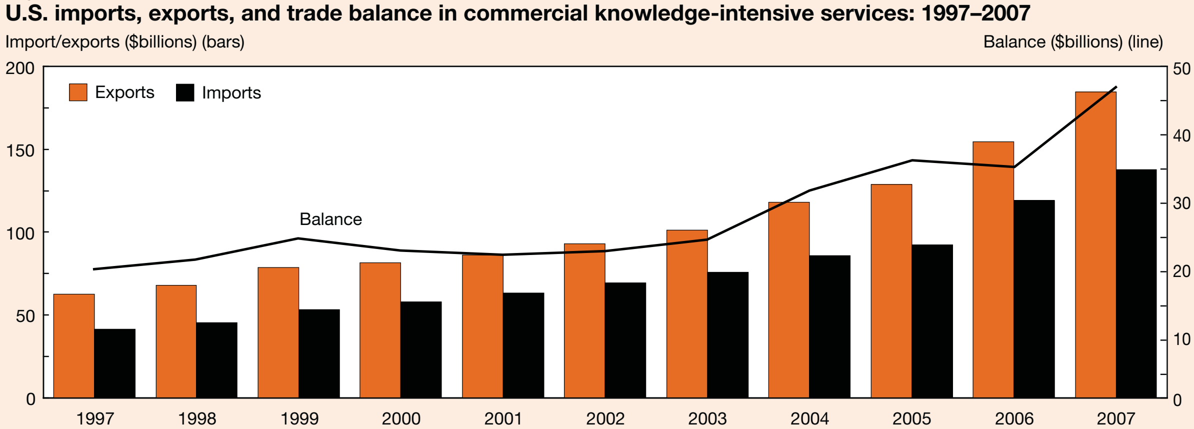
Continued Surpluses From U.S. Trade in Knowledge-Intensive Services and Intangible Assets

Unlike U.S. trade in high-technology products, U.S. trade in commercial knowledge-intensive services—business, financial, and communications services—has produced a consistent and growing surplus (figure O-35). The trade balance widened from $21 billion in 1997 to nearly $50 billion in 2007, as exports grew faster than imports. Likewise, U.S. trade in intangible assets—payments for the use of others' property rights in the production of goods, trademarks, use of computer software, books, records, franchise fees, and the like—exhibited a similar trend of growing surpluses, which reached nearly $60 billion in 2007.

Conclusion

Science and technology are no longer the province of developed nations; they have, in a sense, become "democratized." Governments of many countries have firmly built S&T aspects into their development policies as they vie to make their economies more knowledge- and technology-intensive and, thereby, ensure their competitiveness in a globalizing world. These policies include long-term investments in higher education to develop human talent, infrastructure development, support for research and development, attraction of foreign direct investment and technologically advanced multinational firms, and the eventual development of indigenous high-technology capabilities.

Figure O-35
U.S. imports, exports, and trade balance in commercial knowledge-intensive services: 1997–2007



SOURCE: IHS Global Insight, World Trade Service database, special tabulations.

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The resulting developments open the way for widespread international collaboration.[20] The broad trend in this direction is clearly reflected in the rapid growth of international coauthorships of research articles in the world's leading journals.

The developments also carry with them competitive elements. The quest for international talent, once largely limited to major Western nations, is now pursued by many, and "brain drain" has evolved into cross-national flows of highly trained specialists. In S&T, nations are eager to establish specialty niches and develop indigenous world-class capacity.

The globalization of the world economy has brought unprecedented levels of growth to many countries, demonstrating that benefits can accrue to all. But the structural changes that are part and parcel of rapid growth bring with them painful dislocations, amplified by the uncertainties and potential changes fostered by the world-wide recession. How these are resolved will inevitably affect the health and development of nations' S&T systems and their place in the world.

Notes

1. The Asia-9 includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Thailand, Taiwan, and Vietnam.

2. The World Bank estimates global gross national income to have increased about 80% over the period (current PPP dollars).

3. These estimates rely on data from the Organisation for Economic Co-operation and Development (OECD) and the United Nations Educational, Scientific, and Cultural Organization Institute for Statistics; they are not precise measures. Reported data are converted to dollar totals using purchasing power parities (PPPs), the local costs of a market basket of goods and services; the accuracy of this standard economic conversion may degrade in the case of developing economies. In addition, estimation of some missing data and variable reporting mean that there is uncertainty about any specific point estimate. The reader's focus is directed to the overall trend, which reflects an internally consistent estimate over time.

4. The latest updated 2007 U.S. R&D estimate is $398 billion; see http://www.nsf.gov/statistics/nsf08318/tables/tab1.xls. The overview uses the most recent OECD number to allow more direct comparison with other countries' values.

5. European Commission, Barcelona European Council, *Presidency Conclusions* (Barcelona, Spain, March 2002).

6. See Joan Burrelli and Alan Rapoport, *Reasons for International Changes in the Ratio of Natural Science and Engineering Degrees to the College-Age Population,* SRS 09-308 (Arlington, VA: National Science Foundation, January 2009).

7. Tertiary education by international convention is broadly comparable to at least a U.S. technical school or associate's degree.

8. Both figures exclude those with unknown citizenship (1,600 in 2007) and those with degrees in medical/other life sciences. Engineering figures exclude about 630 with unknown citizenship.

9. Michael Finn, Stay rates of foreign doctorate recipients from U.S. universities, (Oak Ridge, TN: Oak Ridge Institute for Science and Education, forthcoming).

10. Both estimates are based on data from a limited number of countries reporting their data, on a full-time equivalent basis, to the OECD.

11. The database used is Thomson Scientific, Science and Social Science Citation Indexes; IpIQ, Inc.; and NSF tabulations.

12. The physical sciences are physics; chemistry; earth, atmospheric, and ocean sciences; and astronomy.

13. The index numerator is the percent of country A's international collaborations with country B; the denominator is B's percentage of the world's international collaborations. See appendix table 5-41.

14. Citation indicators are subject to a number of distortions: self-citation, citation of failed theories, hypotheses, and approaches; citation of domestic vs. foreign articles; language and cultural barriers; etc. However, when aggregated over many articles, citation indicators carry information about the relative use of articles in subsequent work.

15. In these data, USPTO patents are assigned to the location of the first-named inventor.

16. The geographic distribution is based on location of inventor. Multiple-inventor patents are credited fractionally to geographic location.

17. These industry groups are defined by the OECD and form the basis for databases of economic activity that over a large number of the world's economies. Knowledge-intensive services industries include the commercially tradable business, financial, and communications services, and education and health services, which are considered more nearly location-bound and closer to government functions. High-technology manufacturing industries include aircraft and spacecraft; pharmaceuticals; office, accounting, and computing machinery; radio, television, and communication equipment; and medical, precision, and optical instruments.

18. Internal EU trade was subtracted from both the world and EU totals, because the unified EU market structure makes trade among its member states akin to trade among U.S. states.

19. U.S. trade in advanced technology products shows a similar deficit path. These products, defined by the U.S. Bureau of the Census, include computer software, advanced materials, aerospace, biotechnology, electronics, flexible manufacturing, information/communications technology, life sciences, nuclear technology, optoelectronics, and weapons. However, data categorized in this fashion are unavailable for most other countries and differ from other trade data discussed earlier that are based on OECD definitions.

20. See National Science Board, *International Science and Engineering Partnerships: A Priority for U.S. Foreign Policy and Our Nation's Innovation Enterprise,* NSB-08-4 (Arlington, VA: National Science Foundation, 2008).

Glossary

Asia-8: Includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand.

Asia-9: Includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam

Asia-10: Includes China, Japan, India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand.

European Union: The 27 member states of the European Union since 2007 include Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

High-technology manufacturing: Includes air- and spacecraft; pharmaceuticals; office, accounting, and computing machinery; radio, television, and communication equipment; and medical, precision, and optical instruments.

Knowledge-intensive services: Includes commercial business, financial, and communication services and largely publicly supported education and health services. Commercial knowledge-intensive services exclude education and health.