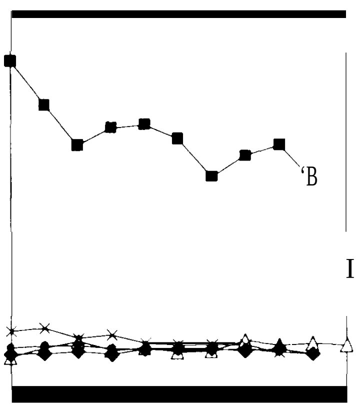
The U.S. Technology Base in Comparative Perspective 3

Despite recent trends in the internationalization of technology, most core innovative activities of MNEs remain centralized in distinct national innovation systems.[1] This chapter compares the structure and performance of the U.S. innovation system with those of other advanced industrial nations.

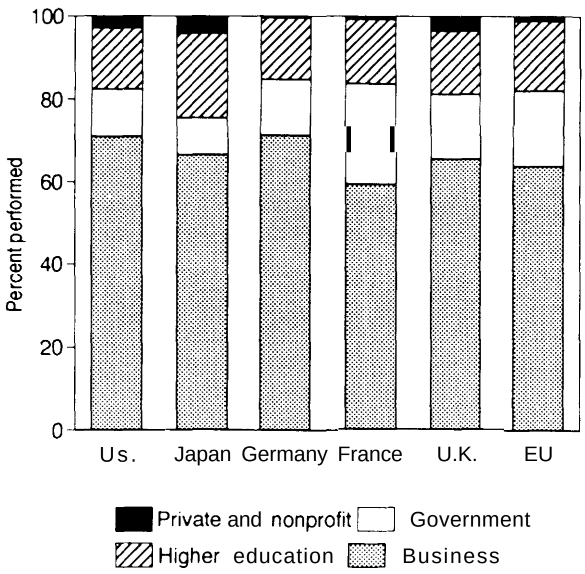
The first half of the chapter examines the principal structural features of each innovation system, which on the whole indicate that the German and Japanese innovation systems are much more oriented toward commercial technologies, while the French, U. K., and especially the U.S. systems direct considerable institutional and financial resources to defense technologies. The French, U. K., and U.S. systems are also characterized by higher degrees of public sector R&D spending and comparatively high levels of foreign funding of domestic R&D, while the German and Japanese systems rely primarily on the domestic private sector for financing national R&D.

The second half of this chapter chronicles recent performance trends across national innovation systems, focusing in particular on the aggregate R&D activities of business enterprises. This section illustrates that the U.S. innovation system remains strong in many respects, but its performance is undercut by comparatively weak R&D investment rates by U.S. businesses, as well as by the



[1] The term "national innovation system" refers to (he broad set of institutions that shape the ability of national firms to develop, commercialize, and diffuse new product and manufacturing process technologies. See R. Nelson (cd.), *National Innovation Systems: A Comparative Analysis* (New York, NY: Oxford University Press, 1993); and G. Dosi, et al., *Technical Change and Economic Theory* (London: Pinter Publishers, 1988).

FIGURE 3-1: Gross Expenditures on R&D: Performance by Sector, 1981-1992 Average



NOTE: European Union data are averages of all EU member states

SOURCE OTA, based on data in Organisation for Economic Co-operation and Development, Economics Analysis and Statistics Division Database, Main *Science and Technology Indicators,* number 1, tables 17-20, May 1994 (hereafter cited as OECD,*STI,* (1), table number, May 1994)

large level of national R&D resources directed to defense technologies.

NATIONAL INNOVATION SYSTEMS: STRUCTURAL DIFFERENCES

Analysts have long noted fundamental differences in the ways nations pursue technological development. Technology policy in the United States often has been described as mission-oriented, in which public resources are directed toward singular, radical innovations designed to achieve prominent national goals—as has been the case in defense, space, and health technologies. The United Kingdom and France also have mission-oriented innovation systems, with a similar orientation toward defense technologies. By contrast, Germany has structured its technology policy to be more diffusion-oriented, where policy facilitates incremental adaptation to change by encouraging the diffusion of new technology throughout the industrial structure. Japan's innovation system is unique among Organisation for Economic Co-operation and Development (OECD) nations, displaying both mission-oriented and diffusion-oriented characteristics.[2]

These different styles of technology policy reflect important differences in the institutional structure of national innovation systems. The following analysis is divided into three sections, each of which examines a principal structural characteristic of national innovation systems: first, which components of the system (e.g., government, business, university) perform most R&D activities; second, which components finance national R&D activities; and third, which technologies or sectors the system emphasizes.

Sectoral Performance: Who Conducts Research

Across the advanced industrial states, R&D is conducted mostly by the business sector, although the level varies from a low of 59.2 percent in France to 71.4 percent in Germany (see figure 3-l). The percentage of U.S. R&D conducted by business (71 percent) is close to that of Germany, while business conducts slightly lower levels of R&D in Japan and the United Kingdom (66.5 and 65.4 percent, respectively). The percentage of R&D conducted by government ranges from a high of 24.6 in France to a low of 9 in Japan. The United States and Germany have fairly similar levels of governmental R&D activity, respectively accounting for 11.4 and 13.4percent of national R&D. In Japan, the higher education sector and the nonprofit private sectors account for relatively high proportions of national R&D (20.3 percent and 4.2 percent, respectively). Higher education

[2] For a discussion of the distinctions between mission-oriented and diffusion-oriented technology policies, see H. Ergas, "Does Technology Policy Matter'?" in B.R. Guile and H. Brooks (eds.), *Technology and Global industry: Companies and Nations in the World Economy* (Washington, DC: National Academy Press, 1987).

elsewhere accounts for approximately 15 percent of national R&D, while the private nonprofit sector ranges from 3 percent in the United States to 0.5 percent in Germany.

The percentage of total R&D performed by each sector provides a basic measure of the raw magnitude and importance of each sector to its respective national innovation system. However, the measure does not fully capture the importance of each sector to the innovative capabilities of each nation, for four reasons. First, the indicator does not account for the quality or significance of R&D; consequently, some sectors may appear more or less significant than they truly are. For instance, higher education in the United States conducts less than 15 percent of all R&D, but the quality and significance of R&D conducted in U.S. universities are widely considered to be unparalleled.[3] Similarly, higher education in Japan accounts for a larger percentage of national R&D than in other advanced industrial states, but the quality and import of Japanese university research is regarded as comparatively weak.

Second, the indicator does not provide information on the character of R&D conducted in each sector. For instance, over half of the governmental R&D in the United States has focused historically on defense technologies.[4] By contrast, governmental R&D in Japan is directed almost exclusively toward industrial technology development.

Third, the measure does not account for the depth and breadth of linkages across sectors, which can affect national innovative capabilities. For instance, strong links between U.S. universities and U.S. industry are critical to the productivity of the U.S. technology base.[5]

Finally, each sector can affect national innovation performance not only by conducting R&D directly but also by financing national R&D efforts. The following section confirms an important observation indicated by figure 3- l—that government plays a significant role in the innovation systems of the United States, France, and United Kingdom, and a comparatively weak role in Japan and Germany.

Financing Patterns: Who Pays for Research

Business and government typically fund most national R&D expenditures. However. business plays a proportionately stronger financing role in Japan and Germany, while government plays a proportionately stronger role in the U. S., France, and the United Kingdom (see figure 3-2).[6] In Germany and Japan, industry finances 61.1 percent and 68.6 percent (respectively) of all national R&D, while government funds a comparatively low 36.8 percent in Germany and 21.5 percent in Japan. In the United States, the government has consistently funded nearly half of all R&D expenditures; only France and, to a lesser extent, the United Kingdom have similarly weighted government sectors. Industry finances approximately 50 percent of total R&D in the United States, and slightly less in France and the United Kingdom. There are similarly pronounced variations in the percentage of gross R&D expenditures financed by foreign sources, ranging from a high of 5.7 and

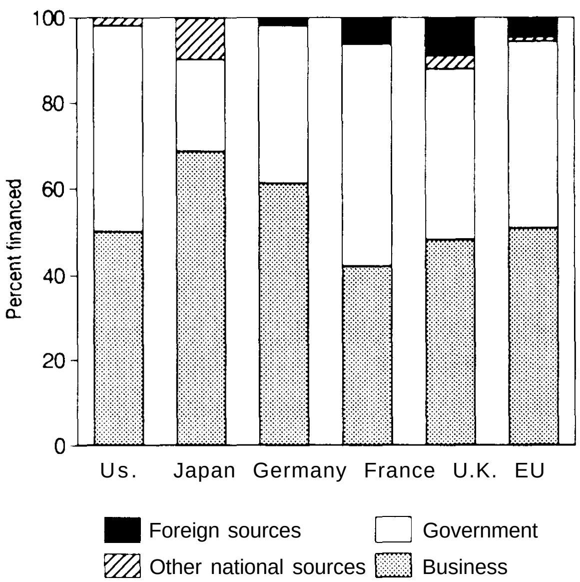
[3] See D.C. Mowery, "The Challenges of International Trade to U.S. Technology Policy," in M.C. Harris and G.E. Moore (eds.), *Linking Trade and Technology Policies: An International Comparison of the Policies of Industrialized Nations* (Washington, DC National Academy Press, 1992); Ergas, op. cit., footnote 2; and Nelson, op. cit., footnote 1.

[4] For additional analysis of this point see the section on gross expenditures on research and development in this chapter. See also J. Alic, et al., *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston, MA: Harvard Business School Press, 1992).

[5] See National Science Board, *Science and Engineering Indicators—1993* (Washington, DC: U.S. Government Printing Of ffice, 1993). pp. 116-127.

[6] Figure 3-2 portrays direct R&D outlays by government, business. foreign sources, and other national sources. R&D also can be supported through indirect channels, such as government procurement practices. Indirect funding mechanisms are, by nature, difficult to measure.

FIGURE 3-2: Gross Expenditures on R&D: Financing by Source, 1981-1992 Average



NOTE: European Union data are averages of all EU member states

SOURCE OTA, based on data in OECD, *STI*, (1), tables 13-16, May 1994

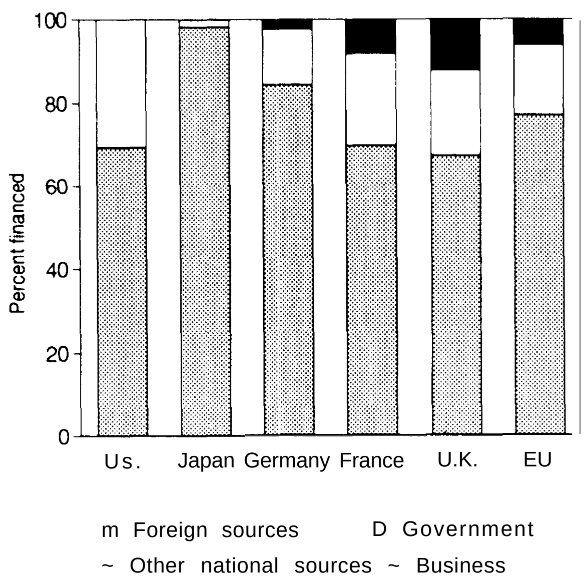
9.1 percent in the United Kingdom and France to a low of 1.6 and 0.1 percent in Germany and Japan.

Patterns in the financing of business expenditures on R&D-as distinct from total national R&D—also reflect differences in the weight of each sector across national innovation systems. As illustrated in figure 3-3, business finances nearly all of its R&D in Germany and Japan (84.3 and 98.2 percent, respectively), while government funds much of the business R&D in the United States (30.7 percent), France (22.2 percent), and the United Kingdom (20.6 percent). Similarly, foreign sources finance little business R&D in Germany and Japan (2. 1 and 0.1 percent, respectively) but have greater impact in France and the United Kingdom (8.1 and 12.3 percent).

The comparatively large financial contribution of the U.S. government to business R&D indicates that corporate R&D in the United States is less financially self-sufficient than in other advanced industrial countries. In essence, this data implies that U.S. businesses may be less able to independently finance and pursue long-term technology development strategies, relative to their competitors across the advanced industrial countries. In addition, the greater financial self-sufficiency of business R&D in Germany and Japan may indicate that corporate R&D in these two countries is comparatively more self-contained and difficult to access through channels other than direct industry contacts.

Moreover, variations in funding source may stem from differences in national attitudes toward technology development. For instance, the U.S. government funds nearly half of all business R&D, but U.S. business receives little public sector assistance for technology diffusion. With the exception of agriculture and, to a certain extent, health, federal expenditures on both military and civilian research and technology development

FIGURE 3-3: Business R&D: Financing by Source, 1981-1992 Average



NOTE European Union data are averages of all EU member states

SOURCE OTA, based on data in OECD, *STI, (1),* tables 32,35-37, May 1994 have "devoted virtually no attention or resources to support. . . the adoption of new technologies."[7]

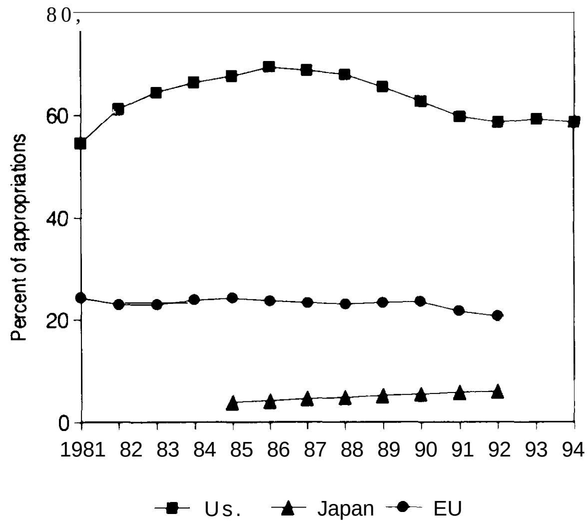
In addition, the U.S. innovation system has a pronounced orientation toward defense technologies. During the 1980s and early 1990s, the defense sector received an average of 63 percent of all U.S. government outlays for R&D, compared to an average of 23 percent for the European Union (EU) and a mere 5 percent for Japan (see figure *3-4).* In the proposed fiscal year 1995 federal budget, defense-related R&D spending comprises 54 percent of federal R&D budget authority; the budget proposes $73 billion for total R&D (a 3 percent increase from 1994 in nominal terms), of which $39.5 billion is directed to defense R&D (a 4 percent increase).[8]

Taken together, cross-national variations in the sectoral performance and financing of domestic R&D efforts reveal a basic structural difference across national innovation systems. On the one hand, the U.S. and to a lesser extent France and the United Kingdom retain innovation systems that reflect the institutional legacy of Cold War defense concerns. On the other hand, Germany and especially Japan have established an institutional structure that largely favors innovation in commercial technologies. An aggregate review of the technologies each system emphasizes reveals additional cross-national differences.

Technological Emphasis: Which Technologies are Produced

As seen in figure 3-1, national R&D across the advanced industrial states is concentrated in the business sector. However, as figures 3-5 through 3-9 show, the sectoral composition and concentration of business R&D varies significantly.[9]

FIGURE 3-4: Defense R&D as a Percent of Total Government R&D Appropriations in the United States, European Union, and Japan, 1981-1994



NOTE: European Union data are averages of all EU member states
SOURCE OTA, based on data In *STI* (1), table 64, May 1994

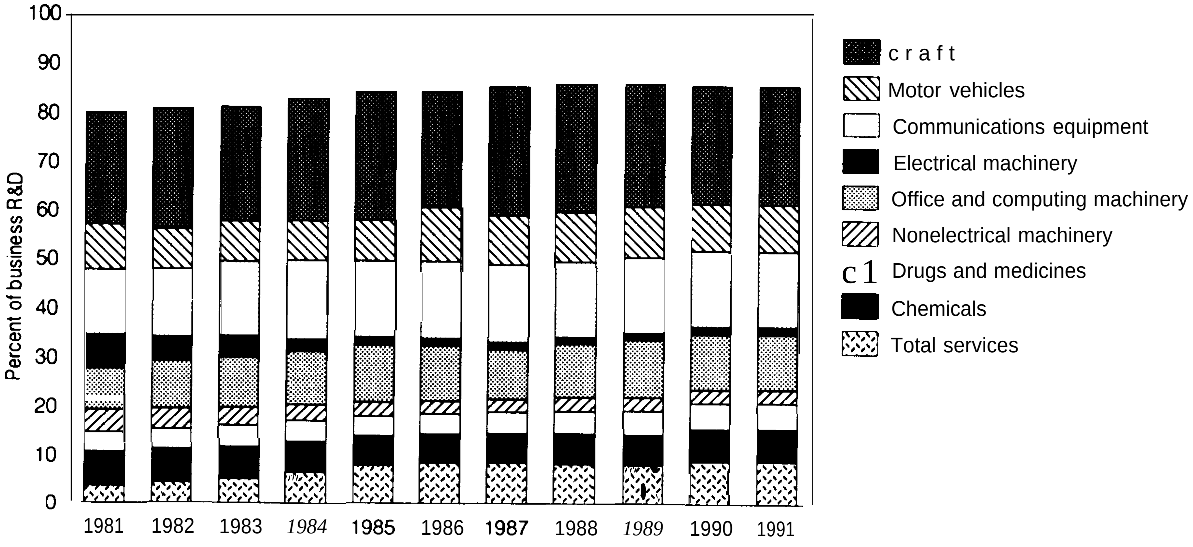
Business R&D in the United States is concentrated in four sectors: aircraft, communications equipment, office and computing machinery, and motor vehicles (see figure *3-5). These* four sectors accounted for 60.7 percent of all R&D expenditures by U.S. businesses in 1991. The aircraft sector consistently represents the largest percentage of business R& D-24.3 percent in 1991. By comparison, in 1991 the communications equipment sector accounted for 15.3 percent of all business R&D, the office and computing machinery sector for 11.4 percent, and motor vehicles for 9.7 percent. The sectoral distribution of U.S. business R&D has been relatively constant over time. The

[7] Mowery, op. cit., footnote 3, p. 124.

[8] Congressional Research Service, Seminar on Proposed FY1995 R&D Budget, Feb.14 1994.

[9] The data in this section have been obtained from the Organisation for Co-operation and Development's Analytical Business Enterprise R& D (ANBERD) database OECD, DSTI (STAN/ANBERD), 1993. See also OECD, *Business Enterprise Expenditure on R&D in OECD Countries: Data at the Detailed Industry Level From 1973 to 1990* (Paris, France: OECD, 1992), pp. 39-41.

FIGURE 3-5: Sectoral Composition of Business R&D in the United States, 1981-1991



NOTES: Chemicals category excludes drugs, electrical machinery excludes communications equipment

SOURCE: OTA, based on data m Organisation for Economic Co-operation and Development, Directorate for Science, Technology, and industry, *Aria-lytical Business Enterprise R&D Database (ANBERD),* (Pam OECD, 1994) ANB/BERD table OI (hereafter cited as OECD/*DSTI, ANBERD,* 1994, table number)

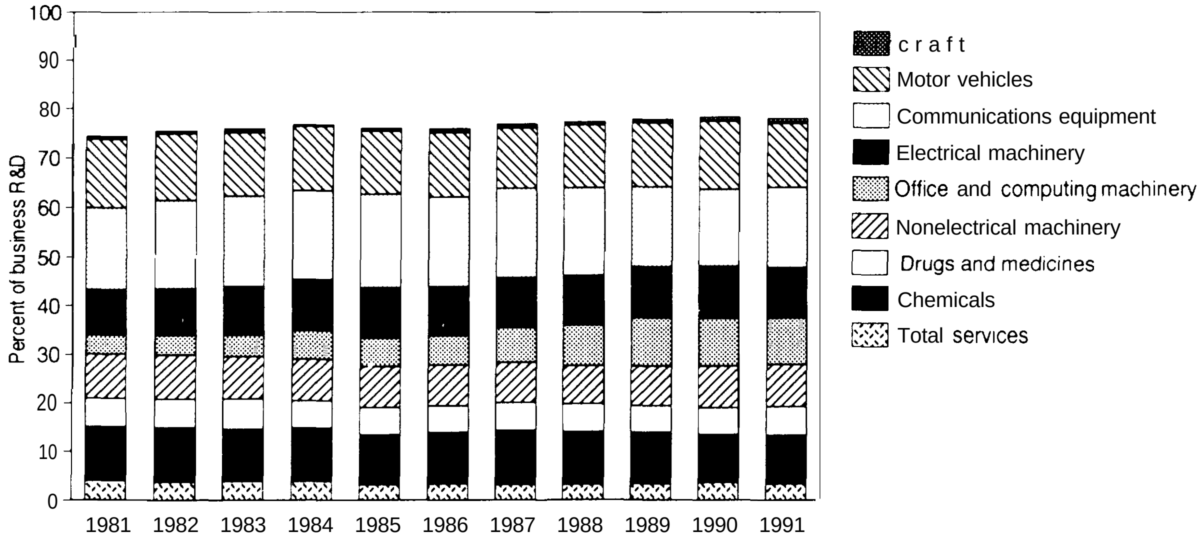
only areas where R&D spending has changed notably have been in electrical machinery (which declined from 6.7 percent in 1981 to 1.4 percent in 1991), communication technologies (which increased from 13.2 to 15.3 percent) and office and computing technology (from 8.5 to 11.4 percent).

By comparison, Japanese business expenditures on R&D are less concentrated than in the United States (see figure **3-6).** In 1991, the top four sectors accounted for 49.3 percent of all business expenditures on R&D, with no single sector dominating the list, as does the aircraft industry in the United States. Moreover, the sectoral emphasis of Japanese business R&D is quite different. In 1991, the communications equipment sector accounted for 16.1 percent of all business R&D expenditures, while motor vehicles accounted for 13 percent, electrical machinery for 10.4 percent, and chemicals for 9.8 percent. This sectoral distribution of R&D expenditures also has been relatively constant over time, apart from office and computing machinery, which increased from 3.8 in 1981 to 9.6 percent in 1991, and chemicals, which decreased from 11 percent to 9.8 percent.

Business R&D in the major European nations is concentrated at levels comparable to that in the United States. In Germany, the top four sectors account for 60 percent of all business R&D, while in France they account for 61.1 percent and in the

10 Since 1980 the greatest rate of change has been in the service sector, which grew from 4. I percent of all business R&D in 1980 to 8.8 percent by 1991. Manufacturing still accounts for over 90 percent of all business R&Din the United States, and therefore remains the analytical focus of this chapter. Some analysts have noted, however, that R&D in the service sector is underrepresented by the available data, and may account for as much as 25 percent of R&D in the United States. See J.A. Alic, "Technology in the Service Industries," *in/ernationu/Journu/ of Technology Management* 9(1*): 1-14, 1994. The* Office of Technology Assessment is currently studying the role of the service sector in the U.S. economy.

FIGURE 3-6: Sectoral Composition of Business R&D in Japan, 1981-1991



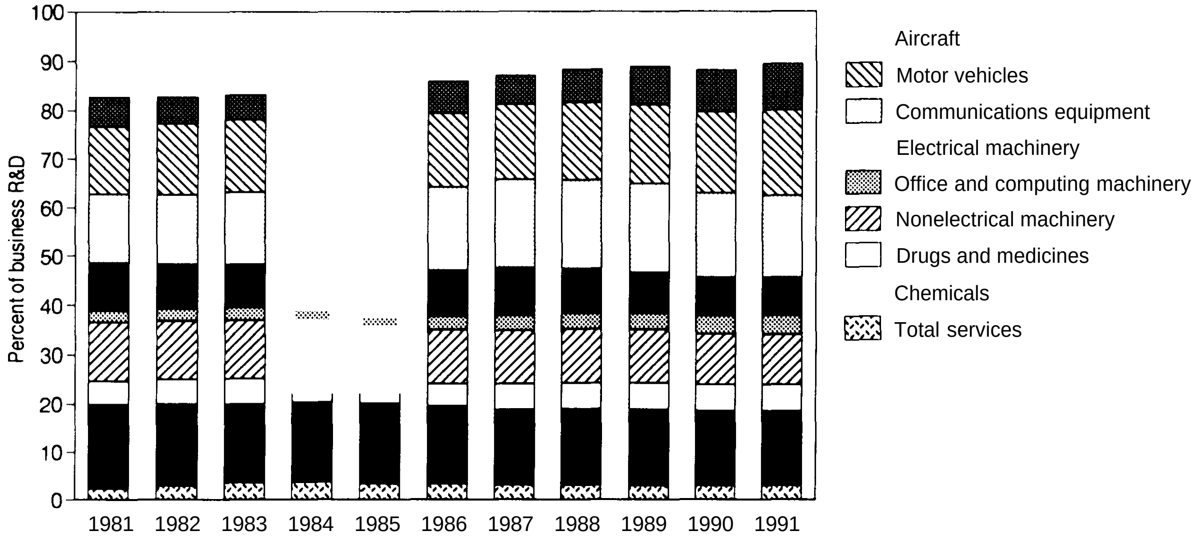
NOTES; Chemicals category excludes drugs electrical machinery excludes communications equipment

SOURCE: OTA based on data in OECD, DSTI/ANBERD, 1994 ANB/BERD table OF

United Kingdom 60.2 percent. However, as figures 3-7, 3-8, and 3-9 illustrate, the sectoral distribution varies somewhat. The communications sector accounts for the largest percentage of business R&D in France and the U.K. (21.8 and 19.9 percent, respectively) and the second largest in Germany (16.8 percent). France and the U.K. also devote considerable resources to the aircraft sector (18.9 and 14.4 percent), which receives a relatively small proportion in Germany (9.4 percent). Germany and France emphasize motor vehicles (17.7 and 11.5 percent), while the U.K. directs only 6.8 percent of business R&D to this sector. The pharmaceutical sector receives a large percentage of business R&D in the United Kingdom (14.4 percent), but a relatively small 7.6 percent in France and 5.4 percent in Germany. Finally, the chemical sector receives a large proportion of business R&D in Germany (15.6 percent), but only 9.9 percent in the U.K. and 8.9 percent in France.

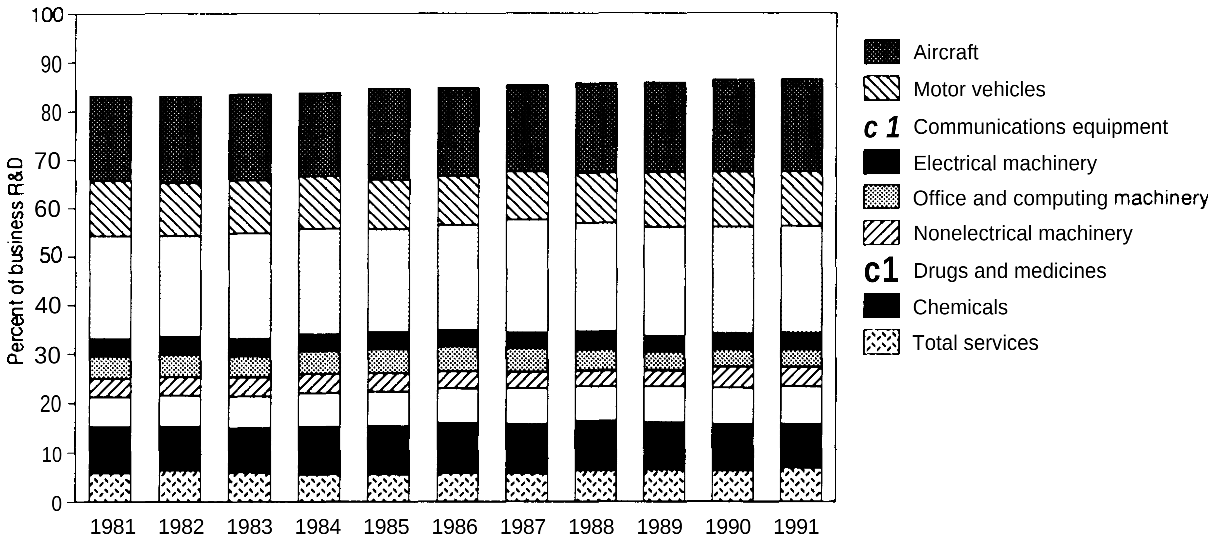
These differences in the national distribution of business R&D expenditures correlate roughly with the sectoral distribution of production across the Triad. As can be seen in figure 3-10, the U.S. share of OECD production is highest in aircraft and lowest in electrical machinery, which corresponds to each sector's relative share of U.S. business R&D. The same relationship holds for Japan's high share of OECD production in communications equipment and low share in aircraft; Germany's relatively high share in motor vehicles and low share in office and computing machinery; France's high share of OECD production in aircraft and low share in office and computing machinery; and the United Kingdom relatively high share of OECD production in drugs and medicines and low share in electrical machinery.

However, there are exceptions to this pattern. Germany's share of OECD production is highest in nonelectrical machinery, which receives a relatively low 9.9 percent of German business R&D expenditures. Likewise, both the French and U.K. share of OECD communications equipment production is low, given that this sector in both countries receives the highest proportion of business R&D (2 1.8 and 19.8 percent, respectively). These and other discrepancies illustrate the broader



NOTES Chemicals category excludes drugs, electrical machinery excludes communications equipment

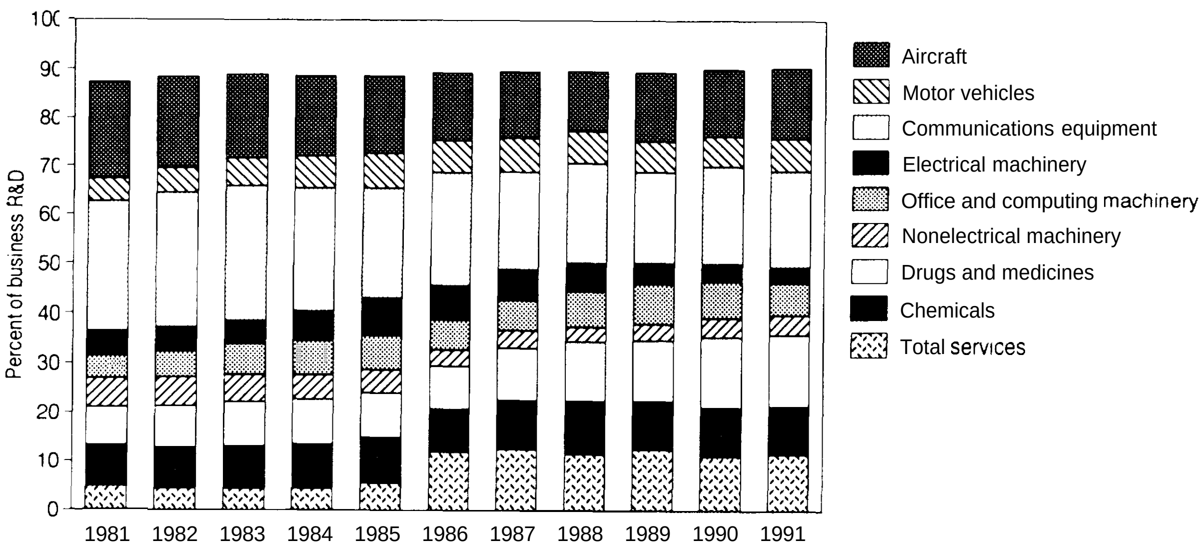
SOURCE OTA, based on data in OECD, DSTI, *ANBERD, 1994,* ANB/BERD table OE



NOTES Chemicals category excludes drugs, electrical machinery excludes communications equipment

SOURCE OTA, based on data in OECD, DSTI, *ANBERD, 1994,* ANB/BERD table 0D

FIGURE 3-9: Sectoral Composition of Business R&D in the United Kingdom, 1981-1991



NOTES: Chemicals category excludes drugs, electrical machinery excludes communications equipment

SOURCE: OTA based on data in OECD, DSTI, *ANBERD,* 1994, ANB/BERD, table OH.

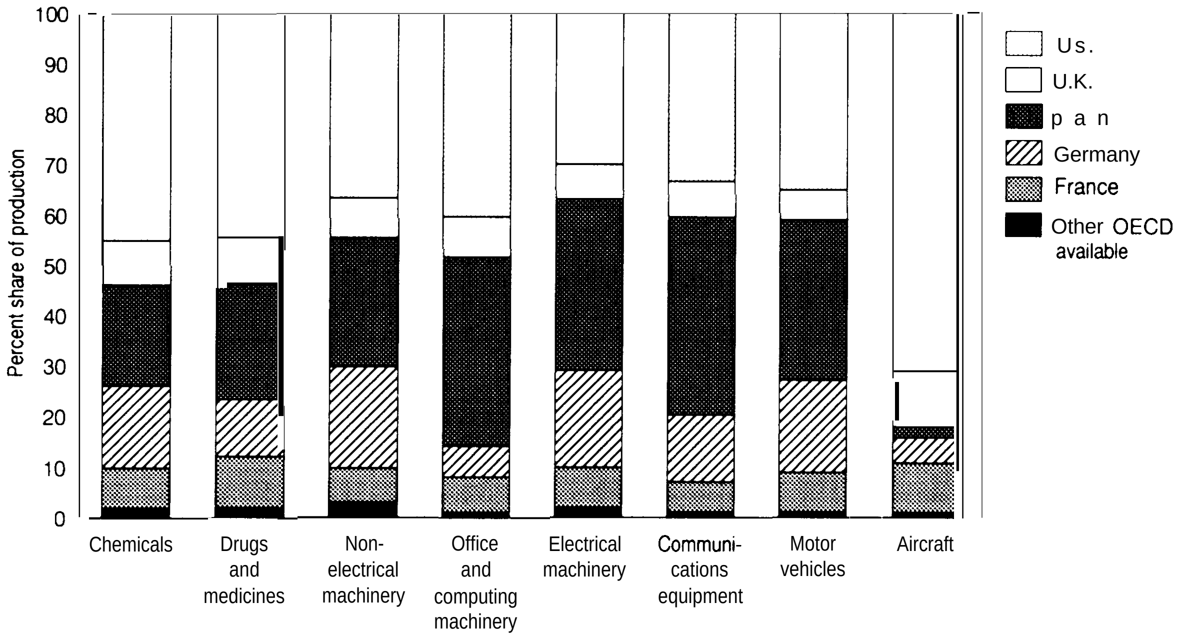
point that it is difficult to link R&D investment rates directly to national, sectoral, or firm-level production and competitiveness. Ultimately, competitiveness at all of these levels is shaped by numerous variables, ranging from corporate structure and strategy to macroeconomic policy and performance. Nevertheless, R&D investment rates are an important indicator of long-term business strategy, and consequently the sectoral distribution of business R&D provides an important measure of the sectoral emphasis of national innovation systems.

In sum, the marked differences in the sectoral performance of national R&D, the financing of national and business R&D, and the sectoral composition of business R&D reveal important structural differences in national innovation systems. The U.S. system is deeply rooted in Cold War political and security concerns. It is characterized by direct governmental involvement, a high degree of national R&D resources directed to the defense sector, and relatively few R&D resources directed to industrial technology adoption.[11] The U.S. innovation system also stands out by virtue of the high quality and large quantity of R&D performed in the higher education sector.

Although few European countries match the degree to which the United States devotes national R&D resources to defense, the United Kingdom and France are similar in that they also have supported large defense-related R&D budgets and have similar mission-oriented innovation systems. By contrast, Germany (along with Switzerland and Sweden) has devoted comparatively few resources to defense.

[11] For an account of the post-WWII origins of (he U.S. R&D system, see D.C. Mowery and N. Rosenberg, *Technology and the Pursuit of Economic Growth (New* York, NY: University of Cambridge Press, 1989). For a description of the contemporary implications of this system, see Mowery, op. cit., footnote 3. See also J.A. Alic, et al., *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston, MA: Harvard Business School Press, 1992).

FIGURE 3-10: Percent Share of OECD Production in Selected High Technology Sectors, 1990



NOTES: Shares are percentage of total available OECD data, “other OECD” category includes data from countries Included in STAN database only when available for all sectors above, 1990 IS most recent year with complete data for selected countries and sectors, numbers may not total 100 due to rounding

SOURCE: OTA, based on data from Organisation for Economic Co-operation and Development, Directorate for Science, Technology, and Industry, *Structural Analysis Industrial Database (STAN),* (Paris OECD, 1994), production tables OD-OG, 0I, and OM-OP

Among the advanced industrial countries, Japan directs the least R&D resources to the defense sector.[12] The commercial orientation of Japan's innovation system is reflected in its institutional structure. The Japanese government has a modest role in directly funding national and business R&D, while the private sector finances and performs the bulk of Japan's most significant R&D. In addition, Japanese universities and other public forums do not provide the central research role that their U.S. counterparts do. Finally, Japan has great strengths in learning and adapting commercial technology generated abroad.[13]

In their entirety, national innovation systems represent different institutional contexts for the complex set of processes leading from technological innovation to commercial competitiveness.[14]

12 Japan's defense R&D spending is concentrated in the Technical Research and Development institute (TRDI) of the Japan Defense Agency. The TRDI's R&D budget is quite modest relative to Japan's total R&D spending, although its programs often benefit from commercial R&D in dual-use technologies. See U.S. Congress, Office of Technology Assessment, *Global Arms Trade*, OTA-ISC-460 (Washington, DC: U.S. Government Printing Office, 1991): pp. 116-120.

13 See R.J. Samuels, *"Rich Nation, Strong Army": National Security and the Technological Transformation of Japan* (Ithaca, NY: Cornell University Press, 1994).

14 Currently little is known in a systematic sense about cross-national variances in the various stages between innovation and commercialization. OTA is currently conducting an assessment of the commercialization of new technologies in the United States. In addition, a cross-national assessment of barriers to commercialization is being conducted by National Science Foundation in conjunction with the OECD.

As the following section demonstrates, there are important variations in the performance of national R&D systems. Together, the structure and performance of national innovation systems create different contexts for the innovative activities of MNEs.

NATIONAL INNOVATION SYSTEMS: PERFORMANCE PATTERNS[15]

Gauging the relative performance and capacity of the U.S. technology base is a complex and difficult analytical task. Most major studies conducted in recent years conclude that the U.S. technology base has eroded considerably. Studies by the National Critical Technologies Panel of the Office of Science and Technology Policy, the Department of Commerce Technology Administration, and the Department of Defense have identified weaknesses in critical commercial, emerging, and defense technologies.[16] Broader studies by the National Science Foundation and the Competitiveness Policy Council conclude that trends in R&D investment and technology development processes show disturbing weaknesses.[17] Moreover, since technology is a central determinant of the trade performance and competitiveness of national economies, many have linked the international leveling of technological capabilities with the weakened trade performance and competitive posture of the U.S. economy.

This section uses these and other studies of U.S. technology and competitiveness as a reference point for investigating performance trends across national innovation systems. Although far from perfect, aggregate R&D investment patterns constitute the single best indicator of trends in the innovative capacity of the U.S. technology base. The analysis focuses on aggregate R&D investment by private enterprise, because it accounts for the bulk of national technology innovation and development across the advanced industrial countries. Moreover, since competitiveness has become increasingly linked to technological innovation, corporate R&D has assumed greater strategic significance for nations.[20]

Therefore, the analysis below proceeds in three stages. First, it examines data on business R&D across the Triad, which indicate that U.S. businesses have reduced their R&D investment rates to comparatively low levels. Second, it compares data on total national R&D expenditures across the Triad, which indicate that national R&D pat-

15 Most of the data in this section come from the OECD. R&D data obtained from national governments are notoriously difficult to compare, given different categorization and measurement techniques. The OECD has gone to considerable lengths to adjust the data to account for national variations in reporting, and in some cases to estimate data that national governments do not provide or do not compile.

16 National Critical Technologies Panel, *Report of the National Critical Technologies Panel* (Washington, DC: U.S. Government Printing Office, 1991); and Department of Defense, *Critical Technologies Plan for the Committees on Armed Services United States Congress* (Washington, DC: Department of Defense, March 15, 1990).

17 National Science Board, Committee on Industrial Support for R&D, *The Competitive Strength of U. S. Industrial Science and Technology?': Strategic Issues* (Washington, DC: National Science Foundation, 1992); Council on Competitiveness, *Gaining New Ground: Technology Priorities for America* Future (Washington, DC. Council on Competitiveness, 199 *I). See* also National Science Board, op. cit. footnote *5.*

18 P. Guerrieri, *"Technological"* and Trade Competition: The Changing Positions of the United States, Japan, and Germany," and P.R. Krugman, "Technology and International Competition A Historical Perspective, " in M.C. Hams and G.E. Moore, *Linking Trade and Technology Policies: An International Comparison of the Policies of Industrialized Nations* (Washington, DC: National Academy Press, 1992). See also T.S. Arrison, et al., *Japan's Growing Technological Capability: Implications fur the US Economy* (Washington, DC. National Academy Press, 1992).

19 Although the relative importance of business, government, and university research varies across countries, In most countries and in most sectors (he industrial research lab is the most significant location of technological innovation. See Nelson, op. *cit.,* footnote 1. Of course, the innovative capabilities and activities of firms are shaped by numerous factors external to the firm, including the educational infrastructure as well as direct and indirect forms of governmental support.

20 OECD, Economic Analysis and Statistics Division, *7'he Impact of Foreign Investment on Domestic Economies of OECD Countries* (Paris, France: OECD, Nov.12, 1993), p. 49.

FIGURE 3-11: Business R&D as Percentage of GDP, 1981-1993

NOTES: Breaks in lines indicate unavailable data for Intermediate years: European Union data are averages of all member states

SOURCE: OTA, based on data in OECD, *STI*, (1), table 25, May 1994

terns mirror business R&D trends. And third, it assesses international trends in patenting, which provide the best quantifiable measure of the relative output of national innovation systems.

Business Expenditures on Research and Development

Since World War II, private enterprise has been the central source of commercially significant innovation in most fields. Relative to governments and universities, businesses are well placed to conduct and deploy R&D for a number of reasons. First, because firms use technology directly, they are more likely to understand where new R&D would be most fruitful. Second, businesses can profit from innovation because they can integrate R&D with production and marketing. And third, although they frequently draw on public scientific knowledge, firms often have unique R&D capabilities that derive from practice—indeed, current practioners are most likely to conduct and benefit from R&D because most innovation involves incremental, cumulative improvement to existing technologies.[21]

However, firms based in different nations conduct R&D at markedly different levels. Figure 3-11 portrays total business expenditures on R&D over the course of the 1980s and early 1990s, measured as a percentage of gross domestic product (GDP).[22] Throughout most of the 1980s the U.S. business sector spent more on R&D than any of its major trading partners, averaging just under 2 percent of GDP between 1981 and 1988. However, after peaking at 2.1 percent in 1985, U.S. business

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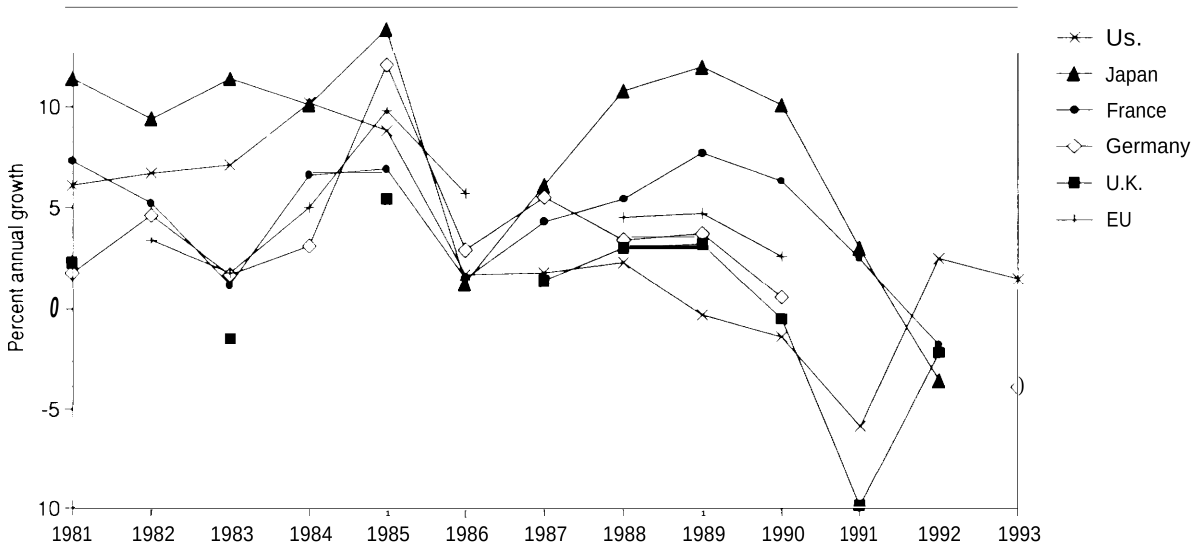
[21] Nelson, op. cit., footnote 1, p.10.

[22] Total business expenditures on R&D should not be confused with R&D financed by business. The former category represents all business R&D outlays, whether they are financed by business itself, government, or other sources. Patterns in business-financed R&D are discussed below; see figure 3-13 and accompanying text. For data on how business R&D is financed in different countries, see figure 3-3 above and accompanying text.

FIGURE 3-12: Compound Annual Growth Rate of Business R&D, 1981-1993



NOTES: Growth rates are based on OECD adjusted expenditures in 1985 dollars As with OTA R&D data, the OECD adjustment employed animplicit GDP deflator breaks in lines indicate unavailable data for Intermediate years European Union data are averages of all EU member states

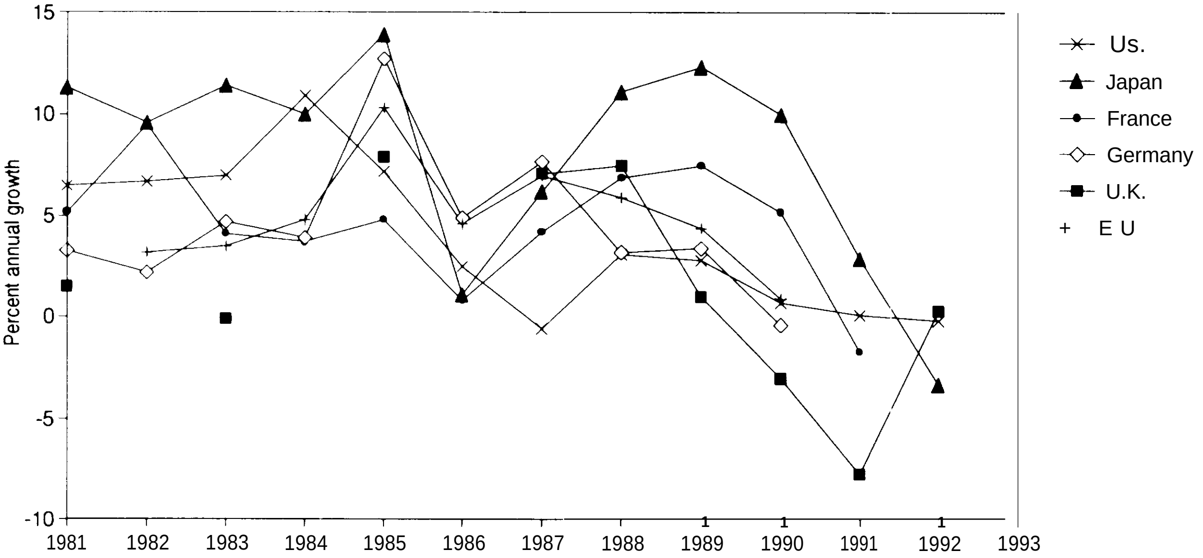
SOURCE: OTA based on data in OECD, *STI (1)* table 23, May 1994

R&D gradually declined to 1.8 percent by 1993. By contrast, Japan's business R&D grew steadily from 1981 to 1990, climbing from 1.4 percent of GDP to a peak of 2.2 percent in 1990, having surpassed the U.S. level for the first time in 1989. After 1990, Japan's level declined slightly, reaching 2.1 percent in 1992. In Europe, Germany has consistently maintained the highest average business R&D rates, with a pattern closely tracking that of the United States. France and the United Kingdom have maintained slightly lower levels, with France's rate growing from 1.2 percent in 1981 to 1.4 percent in 1992, while the United Kingdom's has declined from 1.6 percent in 1986 to 1.3 percent by 1992.

The contrary trends in U.S. versus Japanese business R&D since the mid- 1980s reflects opposite trends in the annual growth rate of R&D spending during that period. As figure 3-12 shows, for much of the last decade R&D spending by Japanese businesses grew at annual rates close to or exceeding 10 percent, although it dropped considerably during adverse economic periods in 1986 and the early 1990s. By contrast, U.S. business R&D growth rates dropped rapidly after 1984, remained low during the expansionary period of the late 1980s, and went negative between 1989 and 1991. In 1992, the U.S. rate increased to 2.5 percent, but then fell again to 1.5 percent in 1993. Between 1986 and 1993, U.S. business R&D grew at an average annual rate of 0.3 percent, compared to 5.7 percent for Japan during the same period. With the exception of the United Kingdom, the major European economies also had stronger growth rates in business R&D than the United States. Between 1986 and 1993, total business expenditures on R&D in France grew at an average rate of 3.7 percent, compared to 2.0 percent for Germany and -0.8 percent for the United Kingdom.

Changes in total business expenditures on R&D do not necessarily imply changes in investment rates by businesses themselves. R&D funding by businesses can come from other sources, including government, other national sources, or

FIGURE 3-13: Compound Annual Growth Rate of Business-Financed R&D, 1981-1993



NOTES: Growth rates are based on OECD adjusted expenditures in 1985 dollars As with OTA R&D data, the OECD adjustment employed an implicit GDP deflator, breaks in lines indicate unavailable data for intermediate years, European Union data are averages of all EU member states

SOURCE: OTA, based on data in OECD, *STI,* (l), table 33, May 1994

foreign sources.[23] However, the changes in business R&D growth rates illustrated in figure 3-12 have been driven less by shifts in government or other nonbusiness financing than by changes in investment outlays by business itself.

Figure 3-13 shows trends in R&D investments financed by business enterprises. In most cases, business R&D expenditures declined during the mid-1980s and early 1990s, generally consistent with national economic trends during those periods. However, there are notable differences in both the rate of decline and the average level over time. Over the last decade, U.S. business stands out for its low R&D growth rates since the late 1980s--despite favorable economic circumstances during much of that period. R&D growth rates for U.S. business declined rapidly from 10.9 percent in 1984 to -0.6 in 1987; although the rate returned to 3.1 percent in 1988, it continued to decline thereafter to -0.2 percent in 1992. The low growth rates since 1987 bring down the U.S. average for the entire period to 3.9 percent.

R&D by German firms also grew at an average rate of 3.9 percent from 1981 to 1993, although it followed a different pattern: it expanded in the early 1980s, remained relatively high in the mid-1980s, and then declined after 1987. R&D growth rates for U.K. firms have been the most volatile, becoming negative in 1983 and again during 1990-1991, and averaging 1.6 percent over the entire period. Of the major European countries, French firms maintained the highest average R&D growth rate of 4.6 percent.

By contrast, growth rates for business R&D in Japan remained close to or over 10 percent throughout most of the 1980s, declining in 1986 and then again in the early 1990s, reaching a negative rate for the first time in 1992. Averaged over the entire period, business-financed R&D in Ja-

[23] See figure 3-3 in this chapter regarding national differences in the financing of business R&D.

pan grew 8.0 percent, over double the rate of U.S. firms.

Apart from U.K. firms after 1988, Japanese business experienced the most rapid rate of decline in R&D growth rates—from 12.3 percent in 1989 to -3.3 percent in 1992. This trend reflects the domestic recession in Japan, the most severe in the postwar period. Further analysis of corporate R&D in Japan, however, indicates that the recession has affected R&D growth rates in some sectors more than others, and that the slower growth rates are likely to be temporary.

OTA interviews suggest that Japanese MNEs have responded to recessionary pressures by cutting unnecessary business costs, reducing labor by encouraging retirement and foregoing new hiring, and looking for new efficiencies through reorganization. These strategies have been extended to R&D as well as production operations. Many Japanese firms have avoided R&D budget cuts by tapering increases in spending levels and shifting resources away from long-term basic research and toward more immediate product development.[24] Japanese firms also have focused their R&D efforts in order to conduct research more efficiently.[25] Through these and other measures, Japanese firms have retained their R&D personnel, maintained steady R&D intensity ratios, and preserved R&D-related plant and equipment investment.[26]

R&D restructuring is likely to be most pronounced in Japan's steel, machinery, electrical machinery, and chemical industries.[27] Japan's computer and electronics industry has also suffered from the recession and scaled back R&D growth rates. Fujitsu cut its 1993 R&D budget by 7.6 percent, and Hitachi by 3.8 percent, while Sony increased its R&D spending by 2.3 percent and NEC maintained a constant level.[28] Japan's top ten R&D spenders show very uneven R&D budget patterns for 1993, ranging from a low of -7.6 percent for Fujitsu to a high of 8.1 percent for NTT, with the average rate of increase for the top 10 being 0.13 percent.[29]

Despite the low aggregate R&D growth rate in 1992 and the strong downturn in important sectors, business R&D spending in Japan is expected to grow by 2.2 percent in 1993 through March 1994.[30] Moreover, survey evidence indicates that Japanese corporations expect their R&D spending plans to be affected only temporarily.[31] In this respect, the mid- 1980s may be a precedent—in

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24 See "' DonaruKigyono R&D: Oyo Kaihatsu Kenkyu—Zentaiteki ni Oyo Shifto," *Nihon Sangyo Shimbun*, p.5, July 28, 1993. According to this survey, the emphasis on applied R&D was particular] y pronounced in telecommunicate (ins, precision instruments, electronics, and medical supplies. For additional survey data showing a shift toward "'defensive" research (e.g. R&D focused on existing operate see "' Donaru Kigyo no R&D Jushi sum Kenkyu," *Nikkei Sangyo Shimbun*, August 9, 1993, p.4.

25 "Japan's Researchers Get Back to Basics," *Nikkei Week/y,* p. 17, Oct. 25, 1993. See also "R&D mo Risutora: Tema Shibori J in in Saihai-chi," *Nihon Kezai Shimbun*, p. 1, July 26, 1993.

26 "Donaru Kigyo no R&D. Jinin Uriagedaka Atari Kenkyuhi—Kaihatsury oku Kakuho Nerai Iji," *Nihon Sangyo Shimbun*, p.5, July 29, 1993, and "Donaru Kigyo no R&D Kanren Setsubi Toshi—Sogaku Shiborarerunaka, Kencho," *Nihon Sangyo Shimbun*, p.5, July 30, 1993.

27 "Japan Researchers Get Back to Basics," and "R&D mo Risutora," op. cit. footnote 25.

28 "'R&D mo Risutora," op. cit. footnote 25.

29 Ibid.

30 Based on a survey covering 392 leading Japanese companies that was conducted by the Nihon Keizai Shimbun Inc. and the Nikkei Research Institute of Industry and Markets. See "'Japan's Researchers Get Back to Basics,"' op. cit., footnote 25. A separate survey of 244 firms also found (hat total corporate R&D budgets were up 2.2 percent from 1992 levels. See "Donaru Kigyo no R&D: Kiso Kenkyu-Chui ni Ikigire Keiko, Joi Kigyo niha Zogaku ga Ooi," *Nihon Sangyo Shimbun*, p.5, July 27, 1993.

31 In the Nihon Keizai Shimbun Inc. and the Nikkei Research Institute of Industry and Markets survey, only 3.4 percent of the respondents expect their R&D spending to decline over the next five years. "The majority of companies want to maintain or expand on past R&D efforts, but in the present economic circumstances they find that very hard to do. The current trend is to focus on a select group of research themes in order to make more efficient use of 1 imited resources. " "'Japan's Researchers Get Back to Basics," op. cit., footnote 25.

1986 corporate R&D rates dropped from very high levels to levels comparable with those of the European Union and the United States, and then rebounded quickly (see figure 3-1 3). Much the same may be happening in the recent downturn. This tendency to preserve R&D investment reflects the oft-noted Japanese penchant for the long-term view, summed up by a Sony executive's comment: "If we cut research and development, we cut our future."[32] This sentiment was echoed by a number of Japanese executives interviewed by OTA.

The staunch effort by Japanese corporations to preserve their R&D budgets contrasts with consistently low R&D growth rates among U.S. firms since 1987, despite a more favorable economic environment during much of the period. Moreover, U.S. firms appear to have made only modest increases in R&D expenditure plans for 1994. The Industrial Research Institute found that only 18 percent of U.S. firms planned to increase R&D expenditures from 1993 levels, while 33 percent expected to decrease; total R&D as a percentage of sales is expected to decrease slightly from 3.5 percent to 3.4 percent .[33] This pattern may reflect continued pressure to constrain costs while quickening product development. The efficiency movement that first hit the factory floor in the 1980s may now be extending to the lab. U.S. corporate R&D strategists are emphasizing R&D productivity and trying to obtain faster product development without additional R&D outlays.[34]

It is difficult to forecast private-sector R&D into to mid- 1990s. However, past trends and current survey evidence point toward sustained national differences in private sector R&D investment. In particular, U.S. firms, compared to their Japanese counterparts, appear less willing and/or able to commit financial resources to R&D over the long term.

Unfortunately, little is known about the central reasons for the relative weakness of U.S. business R&D spending. The most optimistic explanation is that U.S. firms are more efficient in their R&D efforts than are their foreign competitors. To the extent that U.S. firms successfully offset R&D budget cuts by increasing efficiency, the comparatively low growth rates in corporate R&D spending may be less serious than they appear. Similarly, higher business R&D rates in Japan could reflect corporate efforts to overcome an inefficient R&D system. However, although the proposition is logically possible, there is no direct evidence showing that low corporate R&D rates in the United States are offset by greater efficiency.

A second and more common explanation for cross-national differences in business-financed R&D rates points to discrepancies in corporate time horizons. By this account, U.S. firms are less willing to conduct long-term investment strategies because they are more oriented toward short-term return on investment than are most European and Japanese firms. Cross-national variations in corporate time horizons reflect different systems of corporate governance and finance. These systems, and their particular effects on corporate investment behavior, are examined in Part IV of this report.

Over the long term, corporate R&D investment strategies are likely to affect national competitiveness, although the precise effect is difficult to gauge. Linking business R&D expenditures to economic performance is difficult due to a combination of data limitations and the rapid rate of economic and technological change in the U.S.

[32] As quoted in A. Pollack, "Japanese, in a Painful Recession, Trim Industrial Research Outlay s," *New York Times,* p. A 1, Nov. 291993. According to Pollack, Sony's R&D budget is rising I percent in 1994.

[33] "Industrial Research Institute's Annual R&D Trends Forecast," *Research Technology Management 37(1): 15-17,* January-February I 994.

[34] See "R&D Scoreboard: In tbe Labs, the Fight to Spend Less, Get More," *Business Week (3325): 102-127,* June 28, 1993.

economy.[35] In addition, possible differences in the efficiency of national innovation systems indicate that there may not be a perfectly linear relationship between R&D rates and innovative performance. Moreover, R&D investment is just one of several important determinants of innovation and competitiveness. Developing and successfully commercializing new technologies often require large investments in new plant and equipment, new production skills, organizational changes throughout the firm, and new marketing strategies.

Nevertheless, R&D expenditure rates remain a key indicator of long-term investment strategies, and one of the most significant determinants of long-term economic performance.[36] However imperfect the data, few would doubt that technological innovation is strongly associated with private sector R&D. Higher R&D spending alone may be insufficient to generate new technologies, but it is necessary.

The significance of business R&D to national economies is further illustrated by the fact that total R&D trends+. g., the combined R&D efforts of business, government, and academe—mirror the business R&D trends described in this section. As demonstrated below, total U.S. R&D expenditures, although large in absolute terms, have weakened in comparative terms over the course of the last decade, as has U.S. business R&D. Moreover, the commercial significance of total U.S. R&D expenditures is undercut by the U.S. innovation system's longstanding emphasis on defense technologies.

Gross Expenditures on Research and Development

In absolute terms, the United States commits far more resources to R&D than any other nation. As seen in figure 3-14, throughout the 1980s and early 1990s total U.S. R&D spending rose steadily and far exceeded that of other OECD nations. On average between 1981 and 1992, U.S. R&D spending was 53 percent higher than the combined expenditures of European Union member states (it was over 600 percent higher than the European Union's single largest R&D spender, Germany), and 154 percent higher than that of Japan.[37]

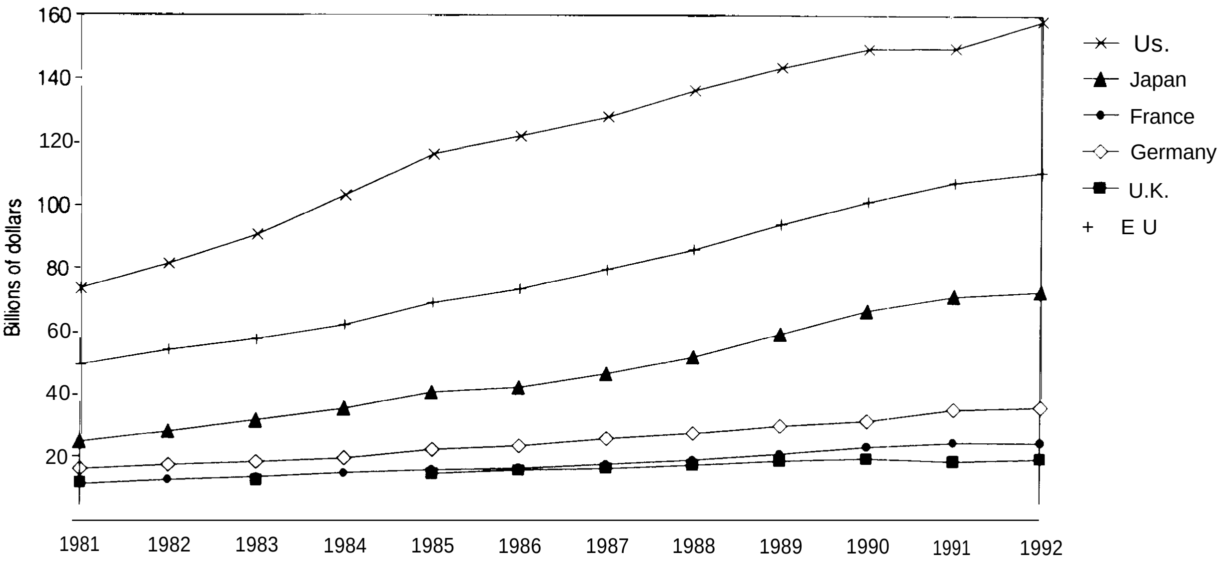
In relative terms, however, aggregate R&D spending patterns reveal more complex patterns. The most comprehensive relative indicator of national R&D efforts measures gross national expenditures on R&D as a percentage of GDP. As seen in figure 3-15, total R&D spending trends across the United States, Japan, and the European Union chart a course that is quite similar to that of U.S. business R&D (see figure 3-11 above). Prior to 1987, the United States consistently maintained the highest R&D investment levels, peaking at 2.89 percent of GDP in 1985. In 1988, however, Japan began leading the world in total R&D rates, climbing from 2.86 percent in 1988 to 3.08 percent in 1990. As of 1992, Japan still led with gross R&D expenditures totalling 2.68 percent of its GDP. Throughout this period European Union member states collectively maintained relatively weak R&D expenditure rates, although some of

[35] Z Griliches "Productivity, R&D, and the Data Constraint," *The American Economic Review 84(1): 1-23,* March 1994.

[36] Z. Griliches, "Productivity, R&D, and Basic Research at the Firm Level in the 1970s" *American Economic Review 76(I): 141-195,* March 1986.

[37] The numbers provided in figure 3-14 are stated in terms of purchasing power parity (PPP). Since countries denominate R&D expenditures in national currency units, it is difficult to compare national R&D data directly. There are two generally accepted methods for comparing R&D data. The first measures R&D as a percentage of GDP, which provides a rough relative indicator of national R&D efforts. This measure is presented in figures 3-15 and 3-17 below. The second method involves converting currencies into a single unit, which allows comparisons of absolute R&D spending levels. The preferred method for converting currencies to compare R&D levels is to use PPPs, which account for international differences in the cost of buying a similar basket of goods and services. For a concise statement of the utility of PPPs for comparing national R&D data, see National Science Board, op. cit. footnote 5, pp. 98-99.

FIGURE 3-14: Gross Expenditures on R&D in Selected Countries, 1981-1992
(purchasing power parity based dollars)



NOTES: The purchasing power parity levels are developed by the OECD's Economic Statistics and National Accounts Division; European Union data are totals for all EU member states

SOURCE: OTA, based on data in OECD, *STI*, (1), table 2, May 1994

the larger member nations were strong on this measure: in 1992 Germany directed 2.58 percent of GDP to R&D, France 2.36 percent, and the United Kingdom 2.08 percent (in 1991).

The relative decline of U.S. R&D investment can be traced to enormous cross-national variations in total R&D growth rates during the 1980s (see figure **3-16).** In all but two years during the 1980s, Japanese annual growth rates in gross R&D expenditures significantly outpaced those of either the United States or the European Union. Total U.S. R&D spending has grown at low rates since 1986. From 1986 to 1988 it increased by approximately 2 percent, then descended to 0.9 in 1989 and even further to negative numbers during 1990-91, rebounding modestly to 1.6 percent by 1992. Between 1986 and 1992, total U.S. R&D expenditures grew at an average annual rate of 1.0 percent. During this time Japanese R&D expenditures increased at an average annual rate of 5.1 percent. For most of the period Japan's gross R&D expenditures expanded at rates exceeding 7 percent, but those rates dropped to 3.2 percent in 1991 and fell negative in 1992.

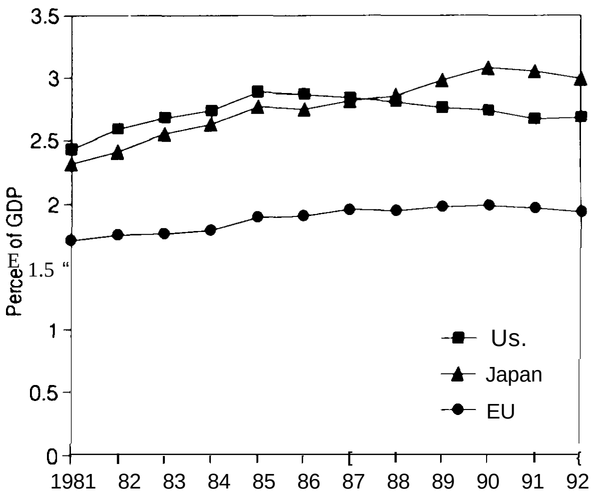
Between 1986 and 1992, total R&D expenditures in the European Union grew at an average annual rate of 3.9 percent. During this period Germany's total R&D spending increased at an average rate of 2.8 percent, while France's spending grew at 3.1 percent. The United Kingdom's total R&D spending declined sharply from rates of approximately 4 percent in the mid-1980s to -5.0 percent in 1991, which brought its average annual R&D growth rate for the period down to 1.0 percent.

Figure 3-16 also suggests that U.S. and Japanese growth rates in gross R&D spending may be converging. In 1992, total U.S. R&D spending grew by 1.8 percent of GDP; in 1993, U.S. R&D expenditures tallied $161 billion, an inflationadjusted increase of 1.6 percent from 1992.38 In Japan, total R&D spending seems likely to increase at a moderate rate. The Japanese government has increased its budget for science and technology by 6.2 percent in 1994 (to approximately $21 billion),[39] while estimates of corporate R&D spending indicate a relatively modest growth rate of 2.2 percent in the fiscal year through March 1994.[40] Even if U.S. and Japanese R&D expenditures grow at similar rates, the trend over the last decade casts a long shadow. Between 1981 and 1992, the compound annual growth rate in total U.S. R&D expenditures averaged 3.4 percent, compared to 6.7 percent for Japan.[41]

From the point of view of commercial competitiveness, U.S. R&D investment rates appear even lower when defense-related R&D outlays are removed from gross R&D figures. Instead of maintaining R&D spending at levels close to those in Japan, U.S. expenditures are more similar to those of Europe, while Japanese expenditures are much higher. As illustrated in figure 3-17, between 1981 and 1991 Japan's total expenditures on civil R&D grew from 2.3 percent of GDP to 3 percent; during the same period, total U.S. investment in civil R&D moved from 1.8 percent to 2.1 percent, and the average of the European Union from 1.5 percent to 1.8 percent. Within the European Union, France's civil R&D expenditures increased from 1.6 percent to 2 percent, while the United Kingdom's remained flat at 1.8 percent.[42]

Figure 3-17 illustrates that, from the point of view of commercially relevant R&D, Japan ranks

FIGURE 3-15: Gross Expenditures on R&D as Percentage of GDP, 1981-1992



NOTE: European Union data are totals for all EU member states
SOURCE: OTA, based on data in OECD, *STI* (1), table 5, May 1994

considerably higher than the United States and other advanced industrial states. For the United States, this comparison may be more relevant than that of gross R&D expenditures because so little of U.S. defense R&D contributes directly to the industrial technology base. Much of the U.S. defense R&D budget is devoted to purely military activities. Of the Pentagon's research, development, test, and evaluation (RDT&E) budget, the science and technology portion—arguably the

38 National Science Foundation, Division of Science Resource Studies, "Data Brief," no. 6, Sept. 24, 1993.

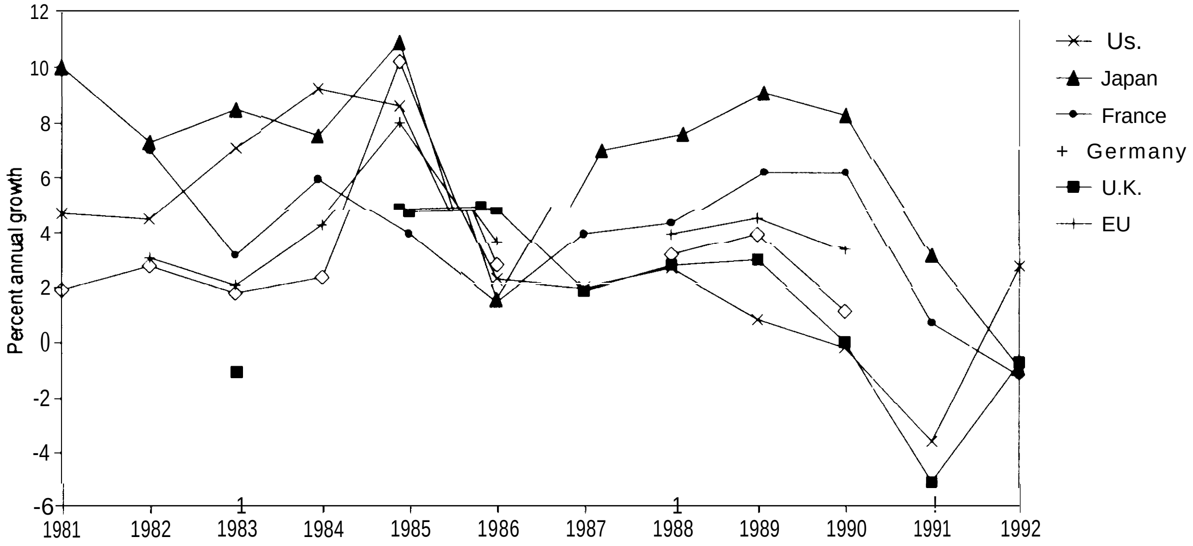
39 Pollack op cit., footnote 32. According to one budgetary analysis, the Japanese government's commitment to R&D remains "rock solid." See J. Choy, "1993 Update on Japanese Research and Development: The Party's Over, " *JEI Report No. 38A,* Oct. 15, 1993.

40 "Japan's Researchers Get Back to Basics," op. cit. footnote 25; and "Donaru Kigyo no R& D," op. cit. footnote 30.

41 Calculated from OECD, Economic Analysis and *Statistics* Division, *Main Science and Technology Indicators* database, 1994 no. 1, table 3 (measured in constant dollars). According to the National Science Foundation, growth in total U.S. R&D in real terms averaged only 0.6 percent per year from 1987 to 1993, compared to the annual increase of 5.2 percent from 1980 to 1987. NSF, "Data Brief," op. cit., footnote 38.

42 Calculated from OECD *Main Science and Technology Indicators*, op. cit. footnote 41, table 6. The OECD does n@ provide estimated figures for Germany's civil GERD. Characteristically, Germany directs comparatively few R&D resources to the defense sector.

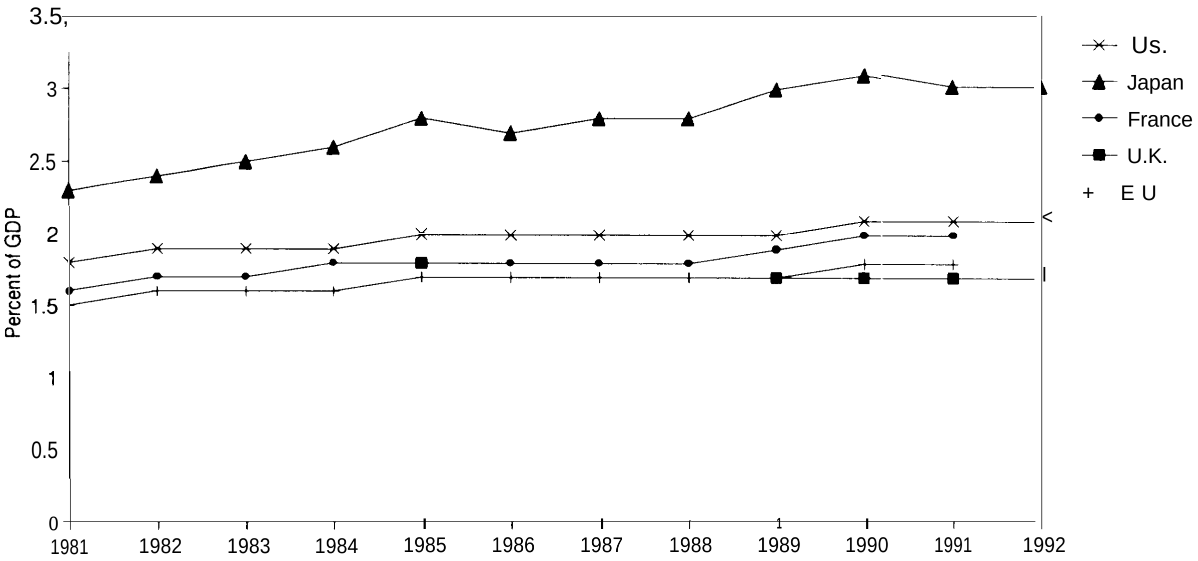
FIGURE 3-16: Compound Annual Growth Rate of Gross Expenditures on R&D, 1981-1992



NOTES Growth rates are based on OECD adjusted expenditures in 1985 dollars As with OTA R&D data, the OECD adjustment employed an implicit GDP deflator, breaks in lines indicate unavailable data for intermediate years, European Union data are averages of all EU member states

SOURCE OTA, based on data in OECD, *ST/,* (1), table 3, May 1994

FIGURE 3-17: Estimated Gross Expenditure on Civil R&D as Percentage of GDP, 1981-1992



NOTE European Union data are totals for all EU member states

SOURCE OTA, based on data in OECD, *ST/,* (1), table 6, May 1994 area with the greatest potential for spinoff effects—totaled less than 50 percent throughout the 1980s, even though the Pentagon's total RDT&E budget ballooned.[43] In fiscal year 1993, 29 percent of the Department of Defense RDT&E budget went to science and technology; the ratio for FY 1994 is estimated to be the same, while the portion requested for science and technology in FY 1995 is slightly lower, at 26 percent.[44] Second, there are longstanding legal, institutional, and administrative barriers that restrict technology transfer between the defense and civil sectors.[45] Third, the spinoff effects of military R&D that in the past contributed to civilian technology development (such as in semiconductors, computers, jet engines, and airframes) have declined substantially in recent years, and in some technologies the flow has reversed.[46] Many observers believe that, in the context of increasingly intense technological and commercial rivalry in the contemporary international system, the historical orientation of the U.S. R&D system toward defense technologies may prove to be more a liability than an asset.

Ultimately, aggregate R&D investment rates provide an important but incomplete view of trends in the innovative capacity of the industrial technology base. Patent data provides a limited but crucial measure of the actual output or performance of national innovation systems. Patent trends can be used to gauge the comparative inventiveness of national systems, the level of foreign patenting within each system, the degree of overseas patenting by residents of individual countries, and the ratio of foreign to domestic patenting.

9 Patents

As with total R&D expenditures, national patenting rates are best measured relative to the size of the economy. Figure 3-18 charts such a measure of national inventiveness: the number of patent applications by residents as a proportion of the population. For most OECD countries, the level of resident patenting activity has been stable over time. The two exceptions are the United States and Germany. The U.S. level increased gradually, from 2.7 per 10,000 in 1981 to 3.5 in 1991, while Germany's level declined from over 5 per 10,000 to 4.1 by 1991 (a trend that may have more to do with the increase in Germany's population after unification than any decline in inventive activity per se). Japan is not represented on this graph because it is literally off the scale. In 1981 Japan resident patent application level was 16.3 per 10,000, and it increased even further to 27.1 by 1991. Japan's high patenting level, however, is due largely to the peculiarities of Japan's patent system. Patent grants in Japan typically have a narrow scope, which encourages multiple filings to cover permutations of an invention that in most OECD nations would be covered by a single patent. Japan's "mosaic" patenting practices make it impossible to compare Japan's resident patenting

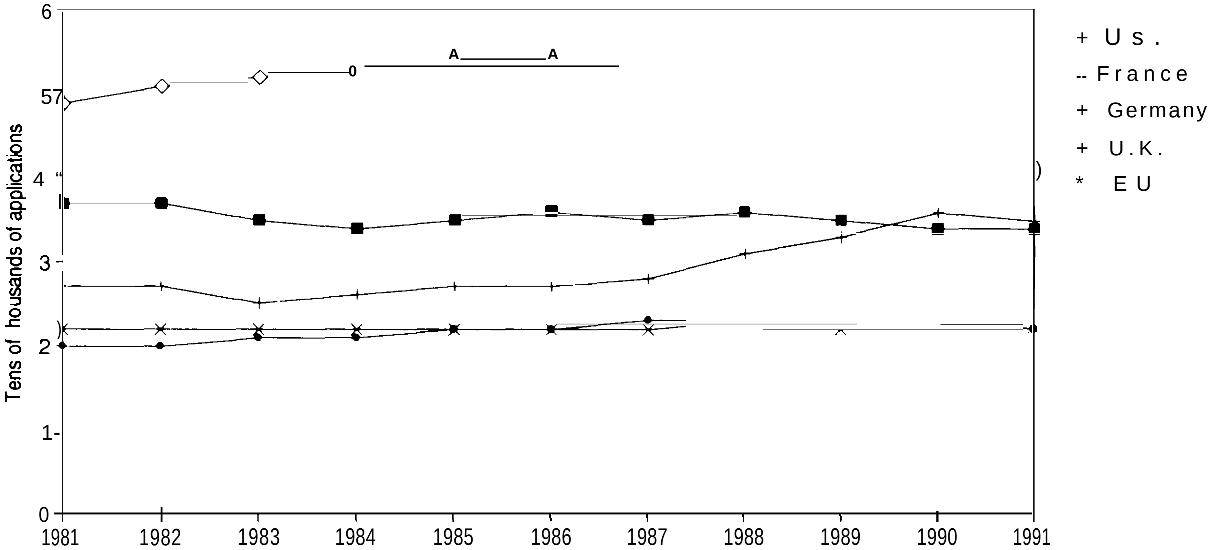
[43] U S Congress, Office of Technology Assessment, *Defense Technology Base: Introduction and Overview*, ISC-309 (Washington, DC: U.S. Government Printing office, June 1987), p. 34.

[44] Calculated from the Department of Defense RDT&E budget FY 1993-FY 1995, as provided by Congressional Research Service R&D Budget Seminar, op. cit., footnote 8.

[45] U.S. Congress, Office of Technology Assessment, *Holding the Edge* (Washington, DC: U.S. Government Printing office, 1989), p. 176.

[46] Alic et al., op. cit., footnote 4. See also Mowery, op. cit., footnote 3, p. 125.

FIGURE 3-18: Resident Patent Applications in Selected Countries, 1981-1991



NOTE: European Union data are totals for all EU member states

SOURCE: OTA, based on data in OECD, *STI*, (1), table 77, May 1994

level with other OECD countries, although it is possible to observe the rate of change. Between 1981 and 1991 Japan's resident patenting level increased 66 percent, compared to a 31 percent increase in the U.S. level.[47]

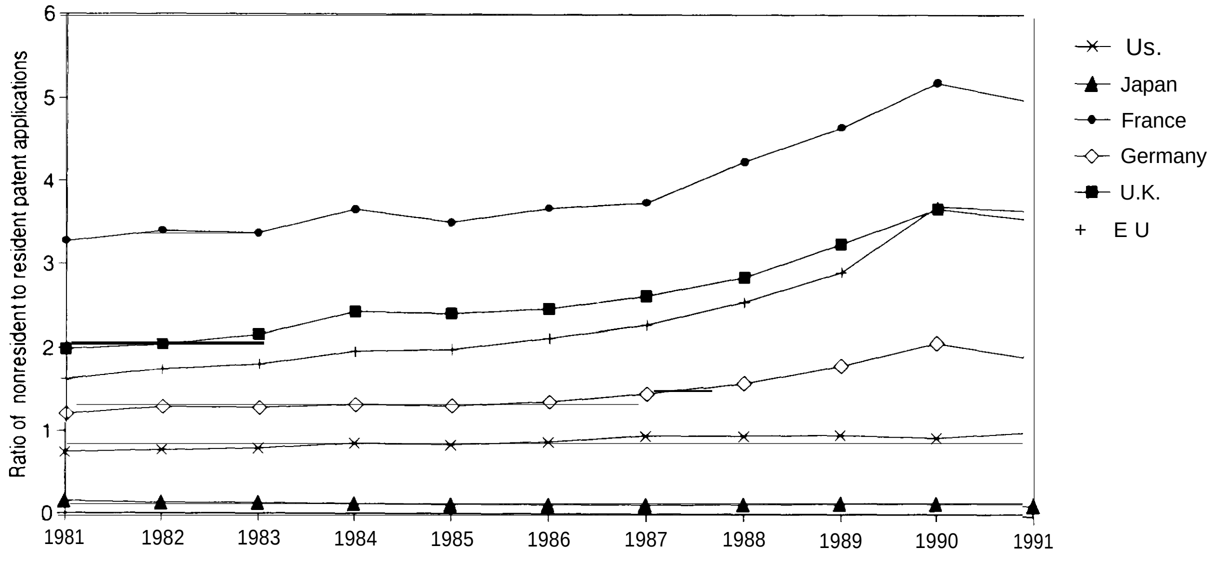
Compared to resident patenting levels, patent applications by nonresidents have increased significantly within most of the advanced industrial states. In the United States, nonresident patent applications rose 91 percent between 1981 and 1991; the level rose 75 percent in France, 70 percent in Germany, 65 percent in the United Kingdom, and 57 percent in Japan.[48] Consequently, in most countries the ratio of nonresident to resident patent applications has increased (see figure 3-19). France, the United Kingdom, and the European Union exhibit the strongest expansion in the ratio of nonresident to resident patenting activity, which reflects the increase in nonresident patent applications during a period of little growth in resident applications. The lowest ratio is in Japan, and it declined from 0.15 to 0.13, reflecting the large growth in resident patenting compared to the relatively smaller growth in nonresident applications. The ratio is also comparatively low for the United States, although it increased from 0.7 in 1981 to 1.0 in 1991 (reflecting the slower rate of increase in resident patenting compared to the large growth in nonresident patent applications). In sum, the different nonresident to resident patenting levels shown in figure 3-19 suggest that there is proportionately more foreign patenting activity taking place in France, the United Kingdom, and the smaller European Union states than in Germany, the United States, and Japan.

The propensity of residents from each of these nations to patent abroad has increased steadily, as indicated in figure 3-20. Although in absolute

[47] OECD, Main *Science and Technology Indicators*, op. cit., footnote 41, table 77.

[48] Ibid., table 73.

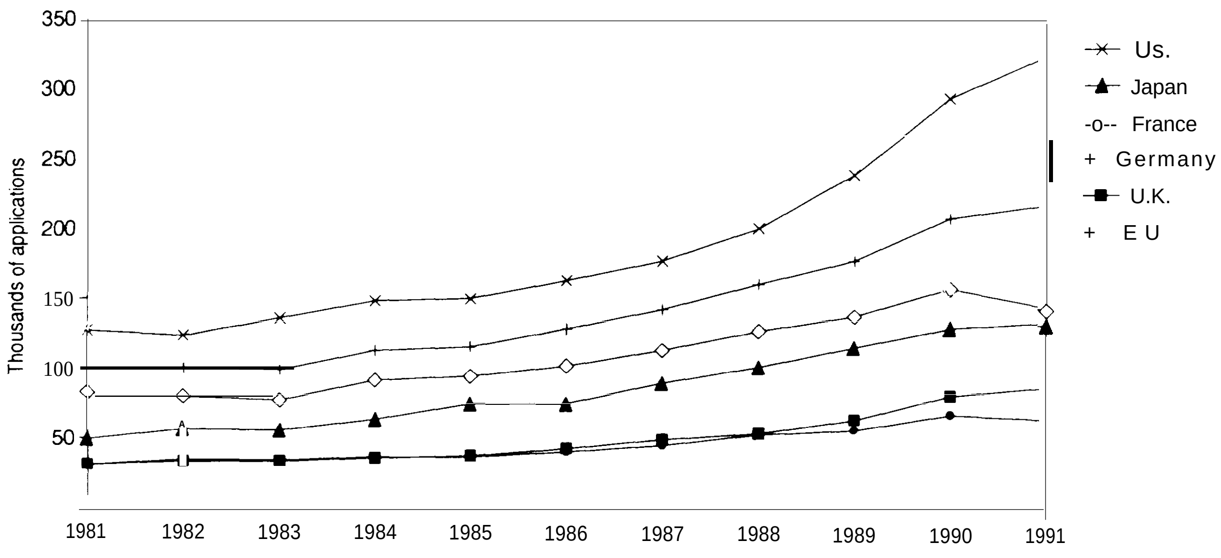
FIGURE 3-19: Ratio of Non-Resident Patent Applications to Resident Patent Applications in Selected Countries, 1981-1991



NOTE European Union data are totals for all EU member states

SOURCE OTA, based on data in OECD, ST/, (I), table 75, May 1994

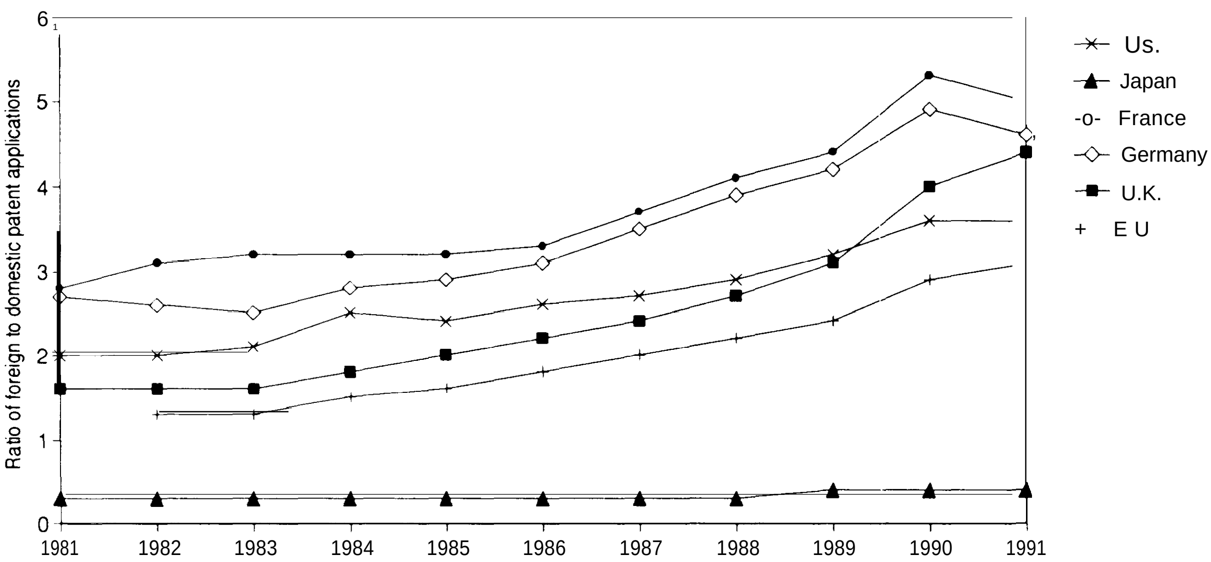
FIGURE 3-20: Number of Foreign Patent Applications by Residents of Selected Countries, 1981-1991



NOTE European Union data are totals for all EU member states

SOURCE OTA, based on data in OECD, *ST/,* (1), table 74, May 1994

FIGURE 3-21: Ratio of Foreign to Domestic Patent Applications by Residents of Selected Countries, 1981-1991



NOTES: Foreign patent applications concern inventions already covered by internal applications, one domestic application can give rise to several foreign applications European Union data are totals for all EU member states

SOURCE: OTA, based on data in OECD, *STI*, (1), table 78, May 1994

terms the United States files by far the most foreign patent applications, the rate of expansion since 1981 has been substantial across the advanced industrial states. The United Kingdom shows the strongest growth in external patenting, increasing 17.5 percent per year since 1981. External patenting by U.S. citizens increased 15.6 percent, while the number increased 17.0 percent for Japan, 10.3 percent for France, and 7.4 percent for Germany.[49]

The widespread increase in external patenting shown in figure **3-20** indicates that firms and individuals are increasingly likely to patent in foreign markets. This trend is confirmed by the ratio of external to resident patent applications, which shows that the internationalization of patenting activity has been increasing steadily for all but Japan (see figure 3-21).[50] These trends suggest that technology has been following the international expansion of business activity. However, as chapter 4 demonstrates, the internationalization of technology has been progressing at a much slower rate than that of production and commerce.

CONCLUSIONS

Taken together, aggregate patenting and R&D trends point to considerable challenges for U.S. technology policy. First, R&D investment rates by U.S. businesses are relatively low, particularly

[49] I bid., table 74.

[50] Again, it is difficult to compare Japan's patent trends with the rest of the OECD due to the unusual character Of Japan's domestic patenting system. The comparatively low ratio of foreign to domestic patenting for Japan, shown in figure 3-21, is partly due to the unusually high level of domestic patenting in Japan. As figure 3-20 illustrates, Japan's level of external patenting has increased substantially, and in 1991 was comparable to Germany's level.

in comparison with Japanese firms. Second, total U.S. R&D investment no longer leads the world as a percentage of GDP. Moreover, the large percentage of total resources devoted to defense technologies reduces the commercial impact of U.S. R&D expenditures. Third, patenting data reveal trends toward the internationalization of technology, as firms and individuals are increasingly likely to seek patents in foreign markets as well as the domestic market. In short, U.S. industry is continuing to invest in R&D at low rates and total U.S. R&D rates are declining in relative terms at the very time that technology is diffusing more rapidly and becoming increasingly internationalized.

At root, the principal mechanism behind the internationalization of technology is the multinational enterprise. The patent trends outlined above measure one dimension of internationalization, but technology can also be internationalized through other business activities, such as overseas R&D, international sales of technology in the form of intellectual property, and cross-national corporate collaboration on technology development. As the following chapter demonstrates, close analysis of these processes indicates that MNEs have magnified the internationalization of technology, but that—relative to their highly internationalized production capabilities—they tend to keep their core technology development functions in the home market. This conclusion describes a central tendency. As chapter four shows, MNEs based in different countries and operating in different sectors often internationalize their core technology development functions in different ways and to different degrees.