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The Structure of Business R&D: Recent Trends and Measurement Implications[1]

Robert Inklaar, Robert H. McGuckin, Bart Van Ark, and Sean M. Dougherty

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1. Introduction

Science and technology (S&T) capabilities are an important policy consideration in the United States, Europe as well as in other developed countries. This is understandable in light of the importance of technology and know-how to productivity, per capita incomes and competitiveness. Recent debate, particularly in the U.S., but also in other countries, has focused on the two interrelated issues, the proportions of research, particularly basic or fundamental research, in R&D expenditures and the location of R&D facilities.

The composition debate is an old one, but it became more of an issue with declines in U.S. government funding of (defense related) research following the collapse of the Berlin Wall. Concerns that basic research expenditures might be too low have been amplified by continuing growth in the share of R&D undertaken by private firms (National Academy of Science (NAS), 1999). This pattern is widespread across countries. In the U.S. the private sector now conducts nearly 70% of total R&D. While the figure is somewhat lower in other countries, the OECD average is about 64%, up from 58% in 1990. Private firms are likely to produce too little basic

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research since such research is likely to generate spillovers (Nelson, 1959; Arrow, 1962). Although government funding increased in the late 1990s, the issue remains.[2]

More recently, the debate has shifted to how the ongoing globalization and offshoring of economic activities is affecting R&D and competitiveness. The increase in the share of R&D undertaken by private firms also fuels this aspect of the debate since private firms undertake overseas investments. The vast majority of overseas investment involves growth and profit opportunities in new and expanding markets and generates profits and exports for domestic firms. Yet, a significant fraction of increased foreign operations involves shifts to take advantage of lower costs. Much of the controversy surrounds loss of jobs and the prospects for slower innovation and reduced security from lower domestic R&D expenditures (McGuckin, 2004).

In this study we examine international flows of R&D with particular focus on flows to and from the U.S. The debate over globalization and the adequacy of basic research has been higher profile in the U.S. This is, perhaps, not surprising since the U.S. is a major source for and direction of R&D funds.[3] The U.S. survey of inflows and outflows of R&D of multinational firms shows steady growth in R&D expenditures by foreign firms operating in the U.S. as well as in expenditures by U.S. firms for R&D in facilities outside the country.

However, even though the U.S. data have some advantages because of the multinational firm survey, they, like the data from most countries, are deficient in many respects. For example, large private firms that conduct most of the R&D are often diversified across a wide range of industries and locations. Company level data distorts industry expenditure information since firms in multiple industries are classified in a single (primary) industry.[4] They also make it

[2] In the U.S. the priorities placed on certain fields of research has been a key concern of many as government funding shifted toward health related research in recent years. Such debate will continue as the opportunities for scientific advance in specific fields of research change and demands for products and services associated with particular services grow and decline.

[3] The U.S. spends much more than other countries on R&D, accounting for nearly 50% of total worldwide expenditures. While much of this lead reflects the size of the U.S. economy, not all of it does. The U.S. devotes a higher proportion of its GDP to R&D. In Europe much of the debate dealt with catch-up and the setting R&D intensity goals. The Barcelona European Council recently set targets to increase R&D spending dramatically from 1.9% of GDP to 3.0% by 2010 (EC, 2002).

[4] Collecting data on a business unit basis was listed as a priority issue by National Research Council (NRC) committee to assess priorities at the NSF Social Science Resources Studies Division in their report, “Measuring the Science and Engineering Enterprise, NRC (2000) at pg. 108-109.

difficult to examine locational decisions, particularly when, as they increasingly do, involve cross border locations.

For these reasons we rely on 42 in-depth interviews with large multinational R&D performers in four high-tech industries to help with interpretation of the observed flows. We also use the interview information to offer some suggestions for improvements in R&D surveys. The interviews suggest that research and development are very different activities and that these differences are closely associated with changing firm organizational structures and the international distribution of R&D.[5]

The interviews were designed to shed light on the composition of R&D activities within the firm, how they are organized, and how they are changing and focused particularly on differences between research and development. We asked companies about the characteristics of each, whether they could distinguish between them in practice and how differences affected the management of each and resources devoted to each activity.

The paper proceeds as follows. Section 2 outlines some recent trends in R&D drawn from surveys by national statistical agencies and provides some context to the globalization debate. In Section 3 we describe the interview process and the sample of firms studied. Section 4 discusses the composition of research and development for the large multinational firms in our sample and the distinctions between R and D. Section 5 looks at the organization of R&D within the firm, how it is changing and how it relates to locational decisions. In Section 6 we use the insights from the interviews to try to better understand the global distribution of R&D and trends observed in the data collected by statistical agencies. In last section we summarize and discuss the overall results, particularly with regards to their implications for data collection.

[5] Although the information we develop has relevance to the debate on the appropriate levels of research, full examination of this issue is well beyond the scope of this study.

2. Research and Development Trends

The 15 years that encompass the decade of the 1990s and the start of the 21st century have been characterized by major changes in R&D expenditure patterns. R&D expenditures as a percentage of GDP, after growing in most countries until the late 1980s, declined through the mid-1990s (Figure 1) The U.S., Japan and Germany resumed growth by about 1995, with France and the UK showing no turnaround till much later. Canada showed very small declines after 1994, but started to grow again soon thereafter. For most countries the recent increases in growth returned the proportion of GDP spent on R&D back to about its 1990s level.

U.S. growth has outpaced other OECD countries (Figure 2) and with the exception of Japan, the U.S. has the highest ratio of R&D to GDP (Figure 3). The lower R&D/GDP ratios for Europe have been a key focus of the debate there. But these ratios probably overstate the differences between countries. In related work Dougherty, et. al. (2004) show that comparisons for manufacturing industries across countries using a specially constructed PPP for R&D and a separate one for GDP, the ratios are much closer than suggested by those shown in Figure 3.

Figure 3 also shows that private industry accounts for the largest proportions of R&D in all OECD countries. It averages about 64% across all OECD countries according to S&T Indicators, 2004. Since 1990 the U.S. has experienced very rapid growth in private industry R&D, particularly relative to federal expenditures, which were very flat until 2001. (Figure 4) Nonetheless, private industry spending on R&D has been growing faster than federal spending since the 1970s, and it was the decline in Federal expenditure growth that accounts for the increasing gap between the industry and government shares of R&D.

While private industry's share of total of R&D increased, the basic research proportion of these expenditures declined in all countries, except France, over the period 1989-2001. Germany experienced an especially large drop, from 5.9% to just 3.9% (Table 1). In the U.S. the decline was nearly 1 percentage points. These declines fueled much of the concerns about the adequacy of S&T programs.

The shift of R&D from manufacturing also plays into the debate. Some have argued that manufacturing is an essential sector for national competitiveness and domestic security (NAM, 2003, for example). The years following the end of the cold war also marked the end of the development and slow diffusion phase of the information and communication technology (ICT) revolution. By 1995 acceleration in the use of ICT technology and the takeoff of the "new" information economy were well underway. Services, but particularly ICT using services, which had been gaining an increased share of developed economies output and jobs, experienced more rapid expansion during this period.

As part of this process U.S. expenditures on R&D outside manufacturing have been increasing since the mid-1990s and now account for about a third of total R&D expenditures, up from less than 20% in 1995. (Figure 5) So while manufacturing accounts for the majority of R&D expenditures, their share is declining. European growth in R&D in services has been slower than the U.S. and as a level they still haven't reached 20% of total R&D. Part of this gap is probably real since ICT diffusion has been slower in Europe than the U.S. (Van Ark, Inklaar and McGuckin, 2003). But it is also likely that the slower growth reported rate reflects the fact that U.S. surveys have put much more emphasis on collecting service sector data than Europe.[6]

Concomitantly, integration of the global economy has spread well beyond the commodities sectors. Services and other intangibles, including R&D have become part of global trade. The U.S. has seen rapid increases in both inbound and outbound R&D with positive net flows to Europe and Canada, but negative net flows to Asia. (Figure 6) The large inflows from Canada are not particularly surprising since it is a part of the North American Free Trade Agreement (NFATA). The large positive surplus with Europe is behind European concerns with R&D intensity, noted earlier. The negative net flows to Asia reflect its rapid emergence as one of the world's major economic regions. For the same reason, there is very little R&D flow between Latin America and Africa and the U.S. since growth and trade are not growing much in these areas.

[6] Europe has been much more proactive on innovation surveys.

3. Firm Sample and Interview Procedures

Interviews of research and development units in highly R&D intensive industries were conducted to develop an understanding of the structure and organization of firms' R&D activities and how they are changing. This work initially focused on the drivers of location decisions. But, in initial interviews and extended discussion with R&D executives of The Conference Board member firms through its Councils program, it quickly became clear that an important factor in location decisions was whether the activity was research or development. It also turns out that this distinction is important in understanding the within-firm organization of R&D across divisional units, as well as its geographic distribution.

The sample of firms was developed after a review of a variety of public and private databases to identify the firms and executives of firms in four of the most R&D-intensive ("high-tech") industries: pharmaceuticals (7 firms/10 units), computers (8 firms/12 units), telecommunications equipment (5 firms/5 units), and motor vehicles (4 firms/6 units).[7] Firms were principally identified using public information from Compustat Global. The individual research or development executives and their associated business units were most often identified through the use of The Conference Board's database of executives in member companies and the idExec database of functional executives.

Almost half of the business units interviewed are located outside the U.S., with 9 in Europe, 7 in Japan, and 1 in China. These research and/or development business units represent 33 unique firms, 29 of which are broadly multinational, with affiliates in numerous countries. About 1/3 have their global headquarters outside of the U.S.

The selected companies have headquarters in the United States, Japan, and Europe, and are all highly internationalized in their sales and production. Of the four main industries we conducted interviews in, the firms in pharmaceuticals are probably the most globally dispersed in terms of research, sales and manufacturing. For instance, although more than half of Johnson and Johnson's sales are in the U.S., it has major R&D facilities in 8 countries and subsidiaries in 55 countries, with manufacturing in all major regions of the world (according to its annual report). Other pharmaceutical companies are similarly structured, except for the Japanese company Fujisawa, which is more heavily focused on its home market.

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[7] A complete description of the firms and industries is included in the Appendix to McGuckin et. al,

The decision to focus on high-tech industries involved our desire to examine firms where R&D was important, industries with many R&D performers and industries that were international in scope. The firm sample shows very substantial coverage of the R&D actually performed in the target industries. Based on comparisons of the R&D intensity of the firms we interviewed the average and median R&D intensities of the industry, the interviewed firms appear to be "typical" R&D performers. The firms we interviewed generally were among the largest in their industries and R&D in these industries is highly concentrated.

As the interviews progressed we found it advisable to extend coverage to firms in several related industries. This helped to provide perspective and context for what we were learning from the initial round of interviews. Moreover, in some cases we used these "other" interviews to refine the structured interviews. Thus, in addition to the industries of direct interest, one "low tech" firm, one small biotech firm, and two firms in more traditional industries were also interviewed. In all, we interviewed 42 different research or development business units, including 35 in person on-site interviews. When time or other factors (transportation) made person interviews impossible, we used telephone interviews (7) and structured follow-up questionnaires.

We used a structured set of questions to guide each interview. The questions were initially developed from a literature survey of empirical work on R&D, and the interviews took as long as two hours. After the first round of interviews, the questions were narrowed to cover a more specific set of issues. In particular we focused on the following distinctions or trends:

- How firms define research and development specifically and R&D as a whole,
- Primary and complementary inputs to R&D production and measures of R&D output,
- Location drivers for R&D activities and the global organizational structure and alignment of R&D functions

(2004).

4. Framing Conceptual Distinctions between Rand D

In this Section we examine differences in R and D as reflected in our interviews. Many of the differences we highlight have been identified in earlier work. But their relevance has become more important in R&D allocation and location decisions. There are many factors at work here, including the rapid development of information and communications technology (ICT), lower transportation and transaction costs and the increased competition that has accompanied them, and the development of new management practices. These forces are generating new organization structures for R and D and they are key factors in the observed patterns of globalization.

Instead of dealing with the many phases of R & D we simply focus on two categories of R&D, namely (1) research and (2) development.[8] Our purpose is to highlight important differences in the demands for R and D, for which outputs are notoriously difficult to measure, and to describe differences in the production of each.

4.1 Distinguishing Research from Development

Typically we distinguish activities by the output they generate, tons of steel, pounds of cheese, value of total sales, etc. But the output of R&D is intangible and not directly observed. For example, research output is typically a technology concept, whose commercial value is uncertain and thus it cannot be linked to a particular product or process. Without some good or service linked to the research idea, differentiating one idea from another is virtually impossible since they are intangible. And counting ideas does not reflect the value of the idea.[9] Moreover, the problem of measuring R&D output is not just a problem faced by social scientists. In virtually every interview this was raised as one of the key problems for R&D executives.

This has led to a large literature on defining R&D that stretches back to at least Vannevar Bush's seminal work on R&D taxonomies in 1945. The terminology and definitions vary but they all distinguish categories of R&D based on the objective of the activity and whether the expected outcome is new knowledge or a new commercial product or process. This motivation

[8] In laying out this simplified version of real world processes we bypass much of the debate and literature on the complex feedback between R and D – the so-called linear versus non-linear model debate (See Nelson, Cohen and Walsh (2002) and Nelson (2003)).

[9] Patent counts are often used as a measure of research output and their values are estimated with citation indexes. While useful, these measures are not wholly satisfactory (See Griliches, 1987).

for distinguishing between R and D is also suggested by recent academic literature ((Rosenberg 1996) (Nelson and Romer 1996)).

"Official" Definitions

The sixth and latest edition (2002) of the Frascati Manual, the international guide for statistical agencies undertaking R&D surveys, contains the following definitions for R&D categories:

- "Basic research is experimental or theoretical work undertaken primarily to acquire *new knowledge* of the underlying foundations of phenomena and observable facts, *without any particular application or use in view."*
- "Applied research is also *original* investigation undertaken in order to acquire *new knowledge*. It is, however, *directed* primarily towards a specific practical *aim or objective."*
- "Experimental development is systematic work, drawing on *existing knowledge* gained from research and practical experience [,] that is *directed* to producing *new* materials, products and devices; to installing new processes, systems and services; or to *improving* substantially those *already produced or installed*."

While we discuss it in more detail below, this focus on basic versus applied research is probably more applicable to academic and nonprofit research organizations than to research in the private business sector. It seems extremely unlikely that today any business is going to undertake research with no potential business relevance. This might have been true for some of the regulated monopolies in the past. It also may be relevant for businesses that obtain large contracts for fundamental work from the government. But business research most likely seeks to fill a business need.

4.2 What the Firm Interviews suggest about the official Definitions

R&D managers felt the Frascati definitions were clear and conceptually appropriate. Yet most also felt that they did not adequately convey the complexity of the R&D process. More importantly, they thought that even though the categories could be distinguished in theory, they found it hard to do so in practice.

R&D managers indicated that virtually all of their research was focused on areas of inquiry and fields of science relevant to the firm's business. That is, they did very little, if any, "fundamental" research or research for knowledge sake alone. [10] The firms undertake a fair amount of research that seeks new knowledge in areas of their business operations, even though the exact commercial processes and products that they expected to emerge from the process are uncertain. But, the general view of research managers was that "true" basic research, research with no application or business need or purpose in mind, was not something they spent much time or dollars on.

In contrast firms describe development as bringing specific new or improved products and process concepts to market. R&D managers generally distinguish it on the basis that it involves a specific commercial application. But the boundary between applied research and development is not a precise line and where it falls in the responses to government surveys is even more problematic. Before dealing with this issue, we turn to the fundamental distinctions in R and D as reflected in the survey.

4.3 Research Outputs are Uncertain[11]

Firms described research as a highly uncertain activity almost always conducted in an area of potential commercial interest to the firm, but lacking a specific commercial application for the foreseeable future, typically defined as two years or less. Whether or not the project is based on new or existing knowledge (or less or greater proportions of new and old) was not a distinction of great importance to R&D managers. These distinctions coincide fairly closely with the Frascati Manuals' separation of basic and applied research. In fact, our interview results suggest that our respondents equate "basic research" with research and "applied research and development" with development as these terms are used in the Frascati Manual (Figure 7).

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[10] They did try to keep track of developments in their fields of inquiry through various forms of university contacts.

[11] An important point to keep in the discussion that follows is that research tends to be a relatively small share of overall R&D. For firms in our sample the percentage varied by industry, with firms in the motor vehicle, telecom, computer and semiconductor industries having research shares in the 1-10% range; except for pharmaceuticals, where it is much higher, in the 15-40% range. The ability of the pharmaceutical industry to sustain higher ratios of research to R&D was by several R&D managers due to the view that in the field of health more basic discoveries can be transformed into commercial applications than in other industries.

R&D managers indicated that the most important distinction was that commercial applications derived from research were not known *ex ante*. Thus, there is a substantial risk that, even if the work is successful, it may not generate a commercially viable product. This risk has two dimensions – technical risk and business risk.

The technical component of the overall risk is the possibility that the research is a dry hole, producing nothing of commercial use. Many firms describe a 1 in 10 chance of success and at least a 3-year plus time horizon for research projects. Although some firms indicate that they experience higher rates of success or use shorter –or longer – time horizons (i.e. 2+ or 5+ years), firms had fairly similar ideas about the uncertain nature of research and what was involved in managing it.[12]

Technical risk has been discussed at some length in the literature. Nelson (1959) emphasized the importance of uncertainty in distinguishing R from D. He argued that the degree of uncertainty in the ex ante results of research were much greater than for development. Nelson is surely right in focusing on the uncertainty of the results of research. It is also clear that the uncertainty is across very different states of nature. As outlined below, development involves clearly defined commercial projects with little technical risk, but substantial business risk.

Aside from the possibility that the research effort fails to find anything new, the interviews also suggest that research carries high business risk. The importance of business risk was emphasized in virtually every interview. The long and unpredictable time horizon associated with research reinforces this risk. One issue is that even if research generates a commercial product, the chance that a competitor introduces the product or a close substitute can be very high.

Firms indicated that, even if they get a commercially viable product, if it does not fit their business plan, it is hard to make use of it. A discovery, however commercially viable, still must be developed, produced and marketed. If the product or process does not fit the firm's business plan, then either another firm must be found for the development and marketing, or the firm must adjust its business plans. Neither option is easy as stressed by many of the R&D managers we

12 Most businesses said they were increasing partnerships with universities and other entities for the more "basic" research that they required. This tends to reduce their exposure by making it possible to include a wider range of projects at the same cost.

spoke with.[13] Thus, a very important business risk facing R&D executives is that the output of the research phase often produces a product or process that doesn't fit the firm's business model.

4.4 Development Output is Well Defined

Research is focused on advancing scientific knowledge and exploring new technologies before determining a specific practical application. In contrast, development involves the improvement of existing products and processes and the creation of new ones. R&D managers generally distinguish it from research on the basis that it involves a specific new commercial application. Moreover, in development projects the output and often the scale of required resources are known at the outset and the time horizons are very short. This means that the level of technical risk for development projects is very low. Time horizons vary but the tendency seemed to be between 6 months and 2 years to commercialization. Since the outcome of the development process and often the required resources are known at the outset of the project, the key risk associated with development is business risk: the risk that someone will come to market with the product before you do or the consumer will not buy it. (Development is characterized by products that fit the firm's business plan.)

While the precise line between research and development is not defined easily, the area has been studied at some length (see Branscomb and Auerswald, 2002). Researchers distinguish late stage research or early stage development as a separate stage of the process. This stage involves determining the feasibility and marketability of specific products. Is the application commercially viable? And can it be produced at a cost that would allow the firm to profit at a price the market would support? This work is described as "advanced" or "early stage" technical development (ESTD) in the interviews. While for some purposes identifying this type of work

[13] This one of the reasons Nelson argued that research was most likely to be undertaken by large firms with diversified product structures: They were more likely to be able to capitalize on the wide-ranging and ex ante unknown results. Estimates of a simple econometric model with data for 1977 by Link and Long (1981) supported the hypothesis. Large diversified firms undertook significantly more basic research. But, using a diversified structure to increase the potential match of research findings and business capabilities isn't likely to represent an optimum business strategy. There is some indication that markets for such products are starting to develop and this tends to reduce the risks associated with commercially relevant findings that are outside the firm's primary activities.

separately is useful, as with applied research it seems best to classify it as part of development as it involves the business decisions.

4.5 Production of Research and Development

As with demand side characteristics, the input proportions used by research and development production processes varied. While there were great differences across fields of science and industries of application, some general considerations applied to virtually all the firms we interviewed. Table 2 shows large differences in the input proportions for R and D.[14] Most of these differences involve labor and material inputs with firms using similar proportions of other current expenses and capital costs.

Research allocates about 60% of its expenditures to labor inputs compared to only 43% for development. These differences directly reflect the composition of their respective scientists and engineers. Ph.D. scientists predominantly do research work, while development is done by a combination of personnel weighted more heavily toward bachelor and masters degrees. The proportion of Ph.D. scientists often reflects the extent to which the work is fundamental – more basic research requires higher skill personnel – and aside from industry there are country differences. For example, Japan is characterized as using fewer Ph.D.s than the U.S., while Europe uses more. Nevertheless, expertise in a particular field was considered to be the most important distinguishing factor for personnel choices, and most of the variation in wages appeared to be associated with technical fields. This is in part because qualifications differ across fields; pharmaceuticals and telecommunications use relatively more Ph.D.s, while motor vehicles use relatively fewer.

Development uses more material inputs, utilizing 31% of expenditures on materials, compared with only 15% for research. It is harder to make general statements about the non-labor inputs, since these vary significantly from firm to firm and from industry to industry. But it is clear that development work uses far more prototypes as inputs than research does. Prototypes are particularly important in the motor vehicles industry, and are also very important in the telecom equipment and computer industries as well. They constitute the bulk of these industries'

[14] Table 2 is based on 13 firms that were able to provide the information in a way that treated overhead expenses in a comparable way

materials expenditures. In the pharmaceuticals industry, expenditures associated with clinical trials consume major portions of development expenditures.

Although we do not have enough observations to break them out by industry or country, we did compare cost structures on a firm-by-firm basis with aggregate R&D data for corresponding industries in each country (from national R&D surveys). Once we do this, we find that development input shares are relatively close to those for R&D as a whole as reported in national surveys. This is not surprising given that development expenditures constitute the bulk of R&D and it suggests that the cost breakdowns in national surveys reflect development fairly well, but not research.

4.6 A Note on Reporting Inconsistencies

What is actually included or excluded from R and D varied widely across companies, even in the same industry. Some research managers in pharmaceutical firms included post-introduction studies in D, while the others did not. In telecom equipment manufacturing, some managers included process work in their plants in D, while many did not. Several of the computer and semiconductor managers include engineering and testing in their D, while the others do not. Inconsistencies arose even within firms. In motor vehicles, engineering and testing done in the research organization was considered to be D, yet some genuine product development carried out outside the research organization was not.[15]

How this plays out in the survey responses is hard to determine. Most research managers are not involved in the reporting process at all. Indeed virtually all the managers we spoke with had never seen the national survey forms. R&D reporting is most often done by firm headquarters, and while they have a good idea about the financial aspects of the firm, they are often not able to disaggregate R&D in particular business units, particularly when R and D units are not separated organizationally.

One of the difficulties in reporting R&D under a consistent framework is the fact that it is difficult to separate out expenditures if they do not coincide with organizational boundaries.

[15] There were some indications that firms located in the U.S. tended to adopt broader definitions. Some U.S. firms did not distinguish R&D from "RDE" or research, development and engineering. At the same time, some firms appeared to devote considerably more effort than others to classifying the scope of their R&D, usually as part of an attempt to obtain the R&D tax credit.

This is why many managers thought the most difficult margin was distinguishing D from engineering and testing because both are associated with the business unit. The organizational changes we discuss next are following the conceptual distinctions in R and D discussed above. Thus firms should be able to distinguish these categories and surveys could start collecting information about research and development separately, not as one aggregated category.

5. Organization of R&D within the Firm

Neither research nor development operates totally independently. A new technology is developed by research, then is handed off to development as specific products or processes are identified, with the researchers staying involved (usually less so over time) as the product moves toward production and the market. However, feedback from development back into research also is important and, it appears, increasingly so. Thus the organizational structure and relationships across the research, development, and operations portions of the firm are key determinants of efficiency and performance.

Not only is organization important, but it is changing dramatically. Nearly two-thirds of the firms we interviewed described substantial organizational changes over the past few years. The general direction of this restructuring appears to have three major dimensions, linking R&D to business needs, increased use of outsourcing and partnerships and new matrix management techniques.

5.1 Making development part of business operating units

In all but two interviews a central R&D laboratory was preserved but more of the work – particularly development – was shifted to business units. One factor in these changes is specialization of function: business has sought to focus R&D resources in the organizational unit best suited to deal with the uncertainties and differences in production processes. A second and interrelated factor is that firms are putting more emphasis on the returns to R&D as part of internal allocation of resources in an increasingly competitive world. This has led firms to direct their scarce research resources to the operations areas that implement and support their business plans.

The certainty of development, its shorter time horizons, and the need to include marketing and production planners in the team creating commercial products makes it more efficient to locate the process in an operational business unit. The interviews suggest that research and development activities are being shifted toward business units as marketers, designers, product specialists, production engineers and financial managers work hand-in-hand with the scientific teams once it appears that a commercially viable product or process is ready for development.

Part of this shift arises from differences in the scale of operations. With development involving much greater scales of operation and very different resource requirements, the stakes involved in making viable commercial decisions are high. For example, specialized and costly safety testing is required for autos and extensive and expensive field tests for drugs. This means that decisions on product development get close scrutiny for their potential profits. In turn this requires resources and expertise well beyond the engineers who develop and apply scientific knowledge.

While uncertainty about the business applicability of research deters individual business units (profit centers) from making independent investments in research, if a clear case can be made that a new product or process can be commercialized over a reasonably short time horizon, they are willing to invest. Moreover, business units' need for new commercial products with profit potential has been expanding as competition has increased. Thus, individual operating business units within a company are increasingly funding early stage development activities. Research, on the other hand, continues to rely more heavily on centralized funding from corporation-wide assessments and government grants.

5.2 Increased outsourcing and partnerships

There are many ways to obtain scientific knowledge and introduce innovation to the firm. Some firms still perform their entire R&D in-house, while others outsource much of their research and/or development to dedicated R&D firms; still others simply license technology from others, or buy it through merger. In most interviews managers indicated increased activity in each of these areas. Simultaneous with the closer alignment of work performed in central labs and business unit needs, much of the higher-risk fundamental research work is being moved to universities and other research partners. Moreover, outsourcing was not simply something that was done in research. Testing and related activities often involve university input and cross-firm collaboration also appears to be becoming more important. In fact, larger firms rely on a wide variety of these "market" sources for their research function. A key implication of this is that outsourcing tends to shift where the R&D expenditures are reported and this can cause major shifts in some industry totals since the activities are reported at the firm level.

5.3 New Management Procedures

Organizational and geographic separation of research and development raises management and strategic alignment issues for firms because the transfer of technology from research units to business units is a critical part of the innovation process. The more independent the research laboratories are, the more difficult it is to smoothly transfer research to business units. In the firms we interviewed, heads of research laboratories have a principal reporting relationship with senior management that is separate but parallel to that of business units that conduct development. And in many firms there was no individual responsible for both research and development. Moreover, it is increasingly common for research personnel to be transferred to business units as projects move toward commercialization, and these transfers can involve a significant proportion of the laboratory research staff. Thus, the organizational structure and relationships across the research, development, and operations portions of the firm are increasingly a focus of firms' efforts to enhance their efficiency and performance.

Managers emphasized the importance of proximity and good communication lines to the market for R as well as D because of the importance of buyer feedback and demand for designing R and D programs. Many executives described the changes as movements toward globally integrated "matrix management," where labs and development functions are consolidated globally across business units. Matrix management is the primary organizational principle for many of the companies we interviewed, but is relatively new, having only been fully implemented on a global basis for R&D organizations in the past several years.

Matrix management techniques play an important and complementary role in the feasibility and efficiency of those organizational changes. In these matrix organizations, particular functions are consolidated throughout the firm, but individuals have both functional and support responsibilities (Beise and Belitz, 1998; Branstetter and Nakamura, 2003 and Chesbrough, 2003). For instance, a research group may be global in its organization, while individual group members also have responsibility to their geographically associated business unit. Thus, for those firms implementing matrix organizations R&D is not usually a fully consolidated function. The heads of the research laboratories typical report directly to the CEO (and less frequently to the CTO) and development is part of business units with executives reporting to business unit Presidents.

Despite the shared responsibility and geographic separate structures, matrix management allows for significant flexibility in making adjustments to projects to exploit technical opportunities and market conditions. Staff can be transferred, work allocations can be shifted, and projects can be restructured relatively quickly (often without physical movement of staff). Information and communications technologies and facilitate these interactions and reduce transportation and communication costs. The new systems enable firms' scientists and engineers to share technologies and solutions using common standards globally and allow companies to integrate their decentralized R, D and operational activities. They also provide ways for firms to internalize gains from R&D at one production facility across a wide range of international operations facilities. However, not all firms are as far along in this type of system-based sharing as others.

5.4. *Locating R and D*

The drivers of location decisions are many, but it is also clear that R is more associated with "academic" centers of excellence and D is more attuned to the structure of the firm's business operations. In many of the U.S. and European firms we interviewed, mergers have also been a driver of changes in the location distribution of the firm's R&D.

5.4.1 Research tends to be close to headquarters and university partners

The nature of research means that it often relies upon close interaction of practitioners and specialized experts. For this reason it tends to cluster around universities and other centers of excellence. In addition, research facilities are frequently close to central headquarters. Part of this appears to be historical (or path dependent), but there is clear desire by managers to locate research projects and teams in close proximity since this offers opportunities for collaboration and cooperation. In fact some managers described internationalization as a restraint on collaboration. Most research projects are primarily conducted in one location. Projects that operate on a “24/7” basis are generally limited to routine technical work.

When research is deliberately internationalized, it is generally driven by the desire to utilize expertise in international centers of excellence.[16] In particular, activities with universities and research centers are a driver for internationalization of research. Yet the motivation typically involved a “push” since they were often motivated by a firm’s view that its home country university systems are inadequate or insufficiently commercial-minded. Several Japanese companies cited this motivation as a reason for locating research facilities in the U.S. and Europe. Analogously, some European companies located laboratories in the U.S. for similar reasons, particularly in the computer industries.

5.4.2 Development is done close to customers and manufacturing operations

Development work is usually located near customers, manufacturing facilities, and suppliers in order to take advantage of local market knowledge and to meet standards or satisfy regulatory requirements. For example, in auto manufacturing, car models are developed to take advantage of local market knowledge, nearby suppliers, and regional manufacturing facilities – which are usually located, near the target market due to high transportation costs. For pharmaceuticals, drugs have country-specific regulatory requirements, unique health care practices, and varying availability of clinical participants. So despite many countries’ recognition of FDA approvals for drugs, there are still strong motivations to do development work in multiple locations. For telecom and computer industries, different regions have different communications standards, needs for unique language interfaces, and varying receptivity to new devices. So firms have incentives to locate development activities near to destination markets.

In all of our interviews, the role of *cost* was not considered to be a major factor in location decisions, particularly for research. It was not that costs were ignored, but executives felt that cost concerns frequently were dominated by other considerations. In work cited earlier we

[16] Some managers described international laboratories as being acquired as part of global mergers and acquisitions that were driven by other considerations.

examined the costs of R&D in manufacturing industries across national borders, developing a R&D specific PPP for the purpose (Dougherty, et. al., 2004). This work suggested that while costs varied across countries, the differences among developed OECD countries where, if anything, shrinking.

For the developed countries covered in this study, the effective differences in costs (typically plus or minus 10-20%) were not considered large enough to affect the distribution of activities across regions, since other factors dominated. In the case of the developing countries China and India, however, managers estimated that even after quality adjustments, it was 50% cheaper to do routine development work there than in the U.S. While these differences clearly account for some offshoring, the key driver of a firm's decision was the need to support its overseas operations. However, given the differences in costs and growth in scientific and technical talent in China and India, the cost differentials may become more important.

5.4.3 Recent empirical studies of R&D locations

The interviews suggest that research will be far less dispersed than development within and outside the firm's headquarters country. Two recent studies develop information on the internal operations of large multinational firms. Gassman and von Zedtwitz (2002) survey 81 technology-intensive U.S. multinationals in order to classify their worldwide R&D sites into those that are research versus development intensive. They find that overseas R&D investment is more than twice as likely to be development-oriented than domestic investment. Research is heavily concentrated in the U.S., E.U., and more developed Asian countries, like Japan and Korea. Of the 299 research units they identified, 280 are in these countries. Development units were more numerous (722 labs) and more widely dispersed, with units in Southeast Asia, Australia, South America, and Africa as well as the countries with research labs.

The second study, Kummerle (1999), surveys 32 multinationals in electronics and pharmaceuticals. Kummerle distinguishes between home base exploiting (HBE) R&D facilities and those that are home base augmenting (HBA). HBE facilities transfer a firm's existing technology overseas, while HBA facilities create new scientific knowledge using host country resources. These categories are in many ways comparable to research (HBA) and development (HBE).[17]

Both studies find similar motivations for the international location of research and development and agree that there are strong differences in the factors driving research and development. Both emphasize the existence of complementary inputs in the location decision, but the complimentary inputs differ. Gassman and von Zedtwitz conclude that companies decentralize research to take advantage of proximity to universities and centers of innovation, access science communities or to make-up for a limited domestic science base. Kummerle uses a logistic regression and finds that a firm's propensity to establish HBA activities increases with its relative commitment to a country, the educational attainment of the labor pool, and the country's scientific achievement. He also finds HBA labs are near universities.

Kummerle finds that HBE labs are located near existing markets and factories. This is consistent with the drivers of development identified by Gassman and von Zedtwitz, local markets and proximity to customers and production. The propensity to invest in HBE also increases with the size of the host country market.

6. Globalization of R&D

R&D has become significantly more internationalized over the past decade as suggested in the earlier discussion of trends. In this section we examine the distribution of research and development and how it has been changing over the last decade and a half using information from national surveys. Most of this discussion is based on survey data, first introduced in Section 2, that show inbound and outbound R&D in the U.S. This provides various cross-country comparisons. This data is obtained from a special survey of firms conducted annually by the U.S. by the Bureau of Economic Analysis as part of the National Income and Product Accounts. The survey enables R&D in the U.S. to be categorized by whether it is undertaken by majority controlled U.S. or foreign firms. Such data are not available for other countries. But there are

[17] The idea of home base exploiting and home base augmenting overseas R&D investments is also explored, although indirectly, in the patent literature (Patel and Vega, 1999; Narula and Verspagen, 2001).

other data, which provide information for other OECD countries. While not directly comparable, the statistical pictures they offer are consistent in many respects.

We then turn to R and D, where D includes applied research. This categorization of R and D reflects what we found in the interviews. Moreover, in light of the important distinctions between R and D, particularly the shift of D to business units, it is important to understand the behavior of each.

6.1 R&D Cross-country Comparisons

Countries differ greatly in the extent to which they are sources and/or directions for R&D investments from other countries. Table 3 shows the proportions of total R&D expenditures that are accounted for by firms based outside the country where the investment is made. The table covers five countries and the EU as a whole for 1989 and 1995 through 2001. Canada and the U.K. are by far biggest recipients in terms of the shares of their R&D funded outside the country. Germany attracts very little foreign R&D and this did not change with the unification of the east and west in 1991. France attracts roughly 10% of its total R&D from foreign sources, although the proportion fell by 1.5 percentage points between 1997 and 2000. Japan has virtually no overseas investment.[18]

6.1.1 Inbound R&D investment to U.S.

Table 4 shows the distribution of foreign affiliate R&D by country of origin. The information covers a number of countries as well as the EU and Asia as a whole. Europe accounts for the bulk of the research inflow to the U.S. and most of this is from the 5 countries shown in Table 4. Germany, the U.K. and Switzerland each with more than a 10 percent share of total foreign R&D in the U.S. dominate, but France also has an 8% share. Taken together these 5 countries account for about 66% of foreign R&D expenditures in the U.S. These same countries accounted for 65% of foreign affiliate R&D expenditures in 1989. But there was much variation among individual countries. But there were The U.K. and the Netherlands showed declines in their shares. The

[18] There are some smaller EU countries; Ireland and Hungary for example are countries that have very high proportions of their R&D supported by foreign sources.

U.K. share of foreign R&D in the U.S. declined slightly, but it remains large, at 19% and The Netherlands' share declined sharply, to 5% from 10%.

Nonetheless, overall European based foreign affiliate R&D in the U.S. fell from 81% to 71% between 1989 and 2001. This was due to the very rapid growth of Asian based foreign affiliate investment, most from Japan, and from Canada. By 2001 Asia accounted for 11% of foreign affiliate R&D, up from 6% in 1989.

A key finding in Table 4 is the large and growing role of foreign affiliate R&D in the U.S. From 9.3% in 1989, the share grew to 13.3 % in 1995 and reached 14.9% in 2001. The expansion in U.S. R&D in the late 1990s means that foreign affiliate R&D grew rapidly in order to keep the share constant. Inbound R&D accounted for around 7 % of total R&D. This proportion grew steadily reaching about 14% in 1994 and remained in the 11 -13% range over the last decade. This movement from 5% to 13% was implies a very high growth rate in inbound R&D. In fact the recent growth of foreign R&D in the U.S. has substantially outpaced growth in domestic-owned R&D, which accelerated from about 3.5% per year in the period 1989-1995 to about 5.5% per year during the 1995 to 2000 period.

6.1.2 Outbound U.S. R&D Investment

R&D performed by U.S. companies overseas has followed different trends. First, inbound R&D by foreign companies is substantially greater than outbound expenditures. Second the rate of growth of outbound expenditures has been much slower than inbound. In 1989 the U.S. invested more R&D overseas than it attracted from abroad (Figure 8). Third, U.S. companies' overseas R&D expenditure has become more dispersed across countries (Table 5) and there has been a change in direction to Asia, particularly areas outside Japan. As noted earlier, this reflects the increased importance of Asia in World growth.

6.2 Research and Development

Examining the global allocation of research and development separately as suggested by the interview data, identifies some important distinctions. Table 6 shows dramatic increases in the "world" share of both research and development performed in the U.S. Here share is measured as the proportion of the total R or D for the five countries, France, Germany, Japan, United

Kingdom, and The U.S., for which we have complete information. The U.S. share of world development increased about 6 percentage points, from 47.4% to 54.5% in the period 1989 and 2001.[19] The U.S share of research also increased over the period from 44.5% to 50.6%. The change was virtually the same as that for development, about 6 percentage points. Since development starts from a much bigger base, R grew much faster than D since the share gains were the same.

With the exception of the U.K., which saw a slight increase in its research share between 1995 and 2001, every other country experienced declines. Even in the U.K., the small gain just returned them to the share of world research that they had in 1989. Japan experienced substantial declines in their shares of both R and D and these mirrored the decline in Japan's GDP. The gains in the U.S. shares also mirrored the acceleration in GDP growth, which increased the U.S. share of world output over the period, from48-53%.

The U.S. share of basic research performed by business increased, despite developments in the share of basic research in R&D. The proportion of business research actually fell from 5.1% to 4.2 % of total business R&D between 1989 and 2001 (Table 7). These figures reflect the concerns of many that the increased proportion of R&D in the private sector is reducing basic research expenditures.

Second, and perhaps more important, even though the share of research in the private sector fell, it has been growing substantially since 1995 (4.2%, Table 8). This represented an increase in the growth rate of private business research of 2.5 percentage points from the 1.7% growth rate in the period 1989-95. In addition development grew faster, accelerating 2.5 percentage points to 6.0%. Thus, even though business research grew at a solid rate, the more rapid growth in development generated a decline in the business research share.

Another factor that helps explain the increase in the U.S. share of world research is the relatively high growth rate of business research in the U.S. The growth of business research in the U.S. was positive, while in comparison, France and Japan experienced declines in the period 1995-2001.

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[19] Changes in development expenditure over the 1989 to 2001 period closely resemble those for R&D as a whole. This is not surprising since D accounts 75-85% of total R&D. For private industry the share is even higher, around 96%.

7 Concluding Comments

The results of the project touch on many aspects of the Science and Technology Enterprise but here we emphasize several factors. First, the activities represented by research (R) and development (D) have very different purposes, production functions; risk characteristics and time horizons characterize R and D. Second, while the generalized characteristics of R and D are similar at most firms, the specifics differ greatly across industries. Third, the difference in R and D is key factor in explaining location decisions and organizational structures within the firm.

Fourth, the scientific enterprise is becoming increasingly international and, spurred by the enabling environment offered by the ICT revolution, is making massive changes in the organization of R&D across as well as within firms. The interviews suggested that the changes enable firms to reduce the costs of R&D by providing closer coordination, better management as well as increased possibilities to exploit its results. Such improvements will tend to reduce the technical and business risk and should lead to higher levels of investment in research (Griliches, 1986). The evidence from the national surveys suggests that the U.S. is experiencing increased R&D investment by business firms and that both R and D are a part of it. In contrast, what evidence we have suggests rates are falling in Europe.

Unfortunately, we cannot say too much more. It is clear that there are many factors that affect research investment decisions. Without a more complete model of the process we must be cautious. Moreover, the time period involved in this study is quite short and may be unrepresentative. The last decade was a time of great growth in the U.S. while Europe has been much slower. There are other possibilities, including differential diffusion rates for ICT technology and matrix management based reorganizations. But without data on how much of inflows and outflows of foreign affiliates are associated with D and R, it is not possible to evaluate the flows in terms of how well they fit the drivers, identified in the interviews, of R and D.

The needs for better information on R&D and the scientific enterprise have been documented by several recent NAS panels and study groups. The current problems with the data echo concerns raised by Zvi Griliches 20 years ago on the occasion of an NBER Conference on R&D, Patents, and Productivity. In his summary remarks, Griliches emphasized the need for more information on the extent to which R&D is basic versus applied and lamented the lack of reliable information on the determinants of R&D investments and their distribution across countries. In particular Griliches was concerned about the lack of information on differences in the cost of R&D in different locations and the distribution of these activities.[20]

In turn several survey recommendations are suggested. First, the definitions of research and development should be clarified and more emphasis placed on the broad distinctions between. Perhaps the most important change would be to begin to focus on collecting information that focus on units and activities within the firm.

This could be done by starting to collect R and D data separately in business surveys. Firms have great difficulty separating applied research from development and development from engineering. Use the distinction that research and applied research or development can are based on the distinction that research work does not have a specific commercial objective, development does. Most firms are able to distinguish research from development. In fact every company we spoke with said that they did not do any research that was not, at the least, in a field of potential business relevance and drawing lines between R and D is becoming easier because new business organization is helping to create clearer boundaries.

Second, and in line with the R and D distinction surveys need to be developed that focus on units within the firm. Reporting of development specifically could be enhanced through a business unit or establishment-based industry R&D survey. Currently R&D surveys are administered on a firm basis. The interviews we conducted found considerable heterogeneity in cost structure and skills required among business units, even within the same firm. Since some of this heterogeneity in diversified firms appears to be systematically linked to industry, surveys at a lower unit of analysis could reveal sharper distinctions in investments across industries and regions.

Third, develop methods to involve the R&D managers in survey response, especially for larger R&D performing firms. In most cases the survey forms are filled in by accounting or finance units in firm headquarters. While some companies suggested that their finance units had a good understanding of the scope of their R&D work, many others suggested that some detailed working knowledge – of development activities in particular – was required to distinguish these expenditures. In fact, there was very low awareness of national R&D surveys' existence among

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[20] Ten years later he broadened his attack in his presidential address to the American Economic Association with particular focus on R&D and the service industries, noting that "great advances in…theory and econometric techniques…will be wasted unless they are applied to the right data."

senior R&D executives. Nearly unanimously, the completion of the RD-1 form is done without their guidance, and most surprisingly, in only a few cases were they able to locate a copy of a recently completed form in their organization.

Finally, increased harmonization of specific survey questions may seem straightforward, but differences between countries' surveys have persisted over many years, despite the Frascati Manual (1963–2002). While there has been much progress, more could be achieved. Given the importance of S&T indicators to policy in all countries better coordination and improved sample designs are needed.

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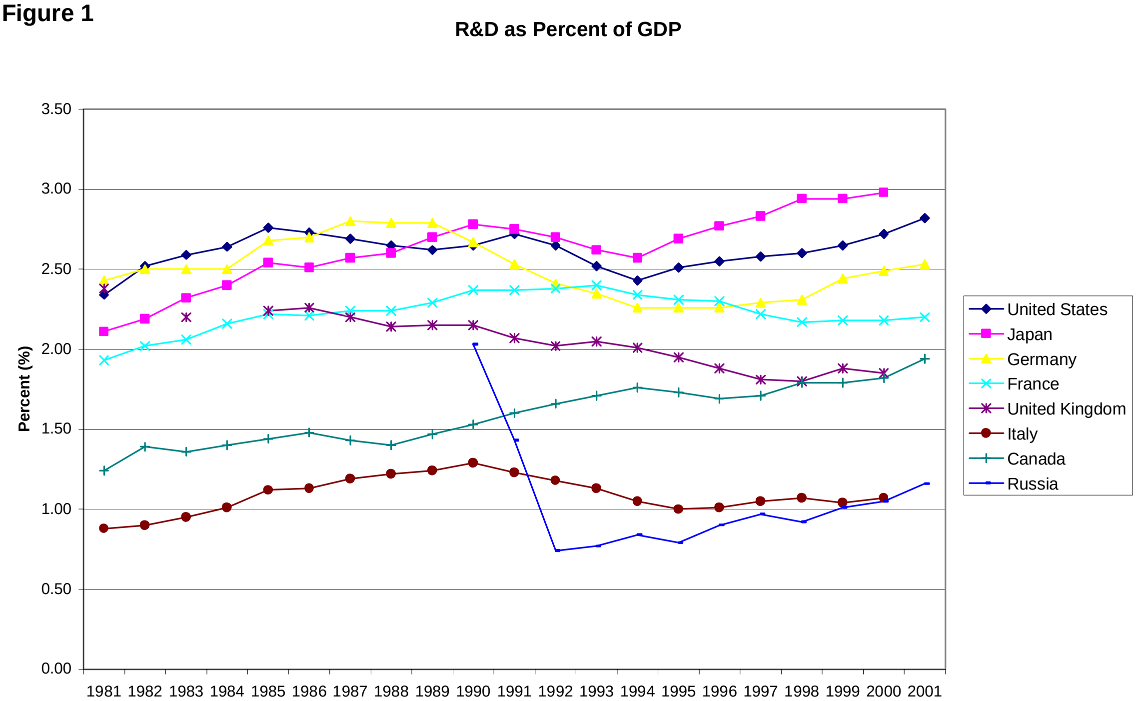
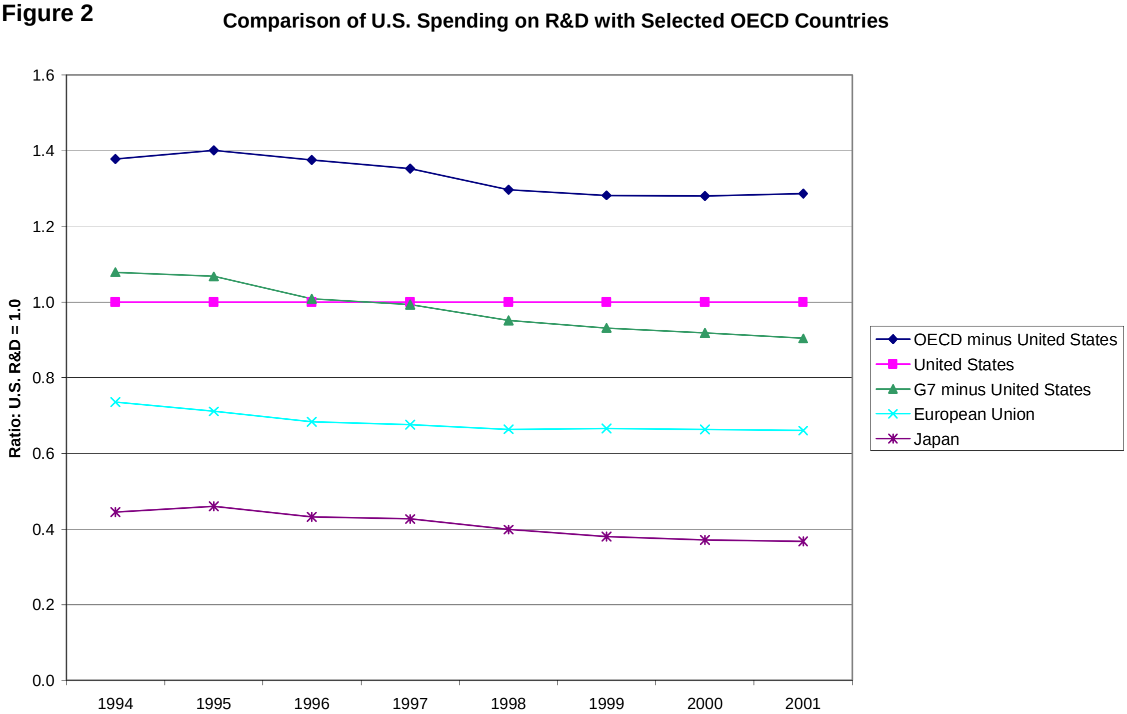
Tables and Figures

Figure 1



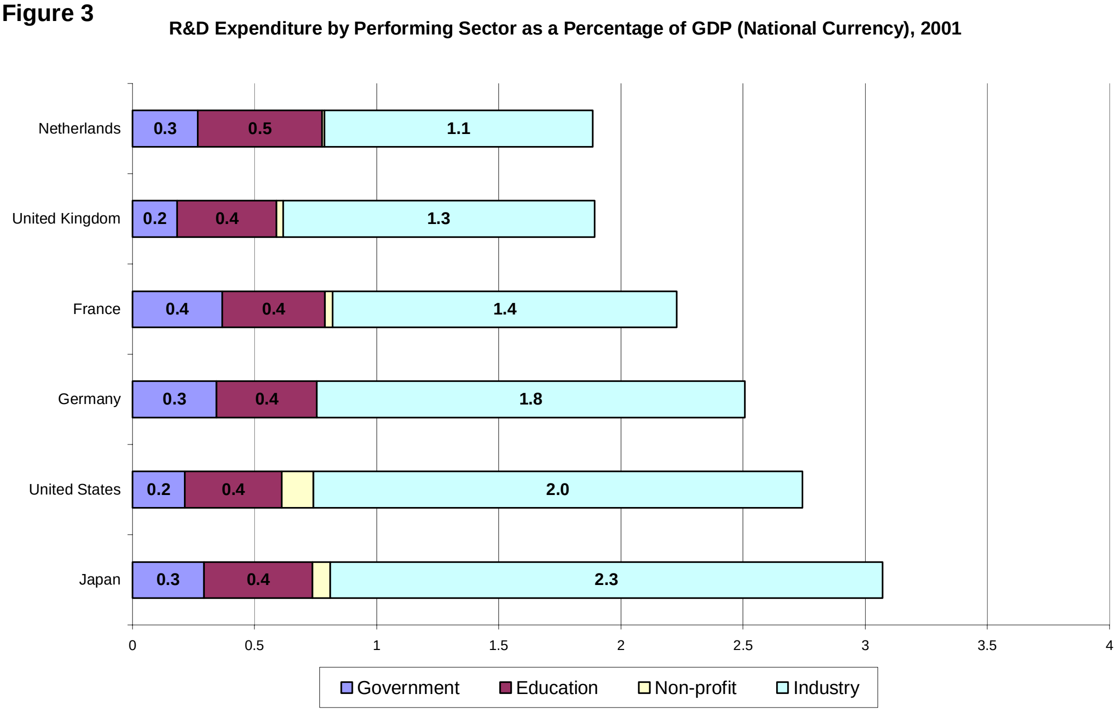
Source: NSF Science Indicators 2004

Figure 2



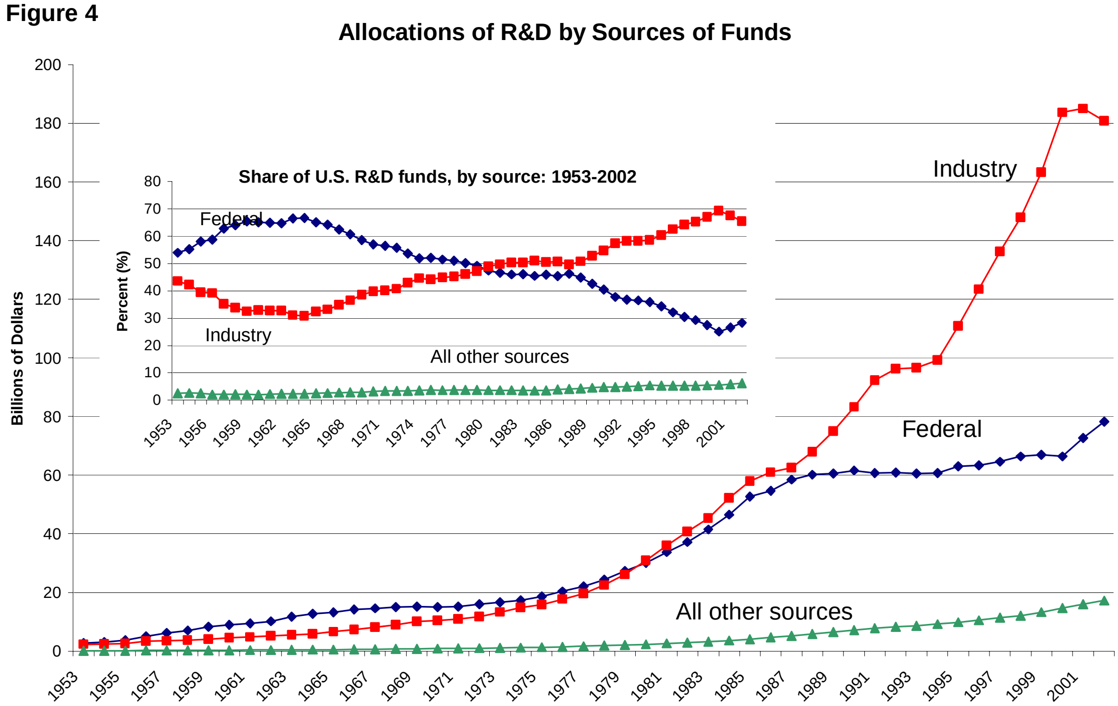
Source: NSF Science Indicators 2004

Figure 3



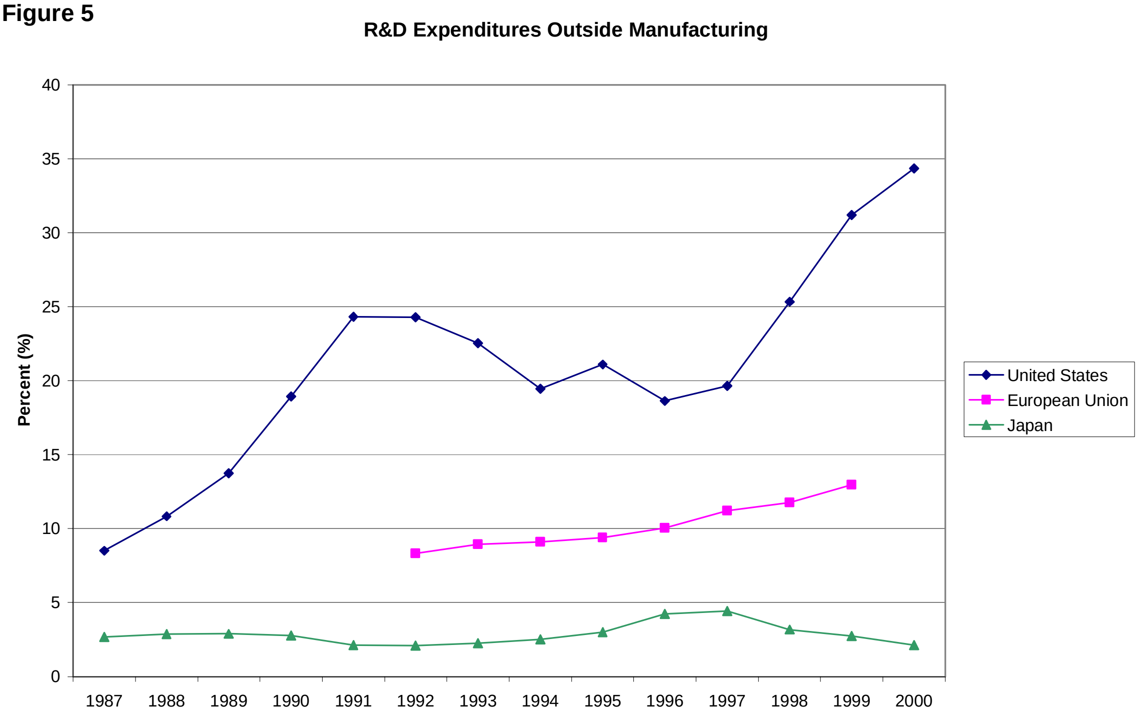
Source: NSF Science Indicators 2004

Figure 4



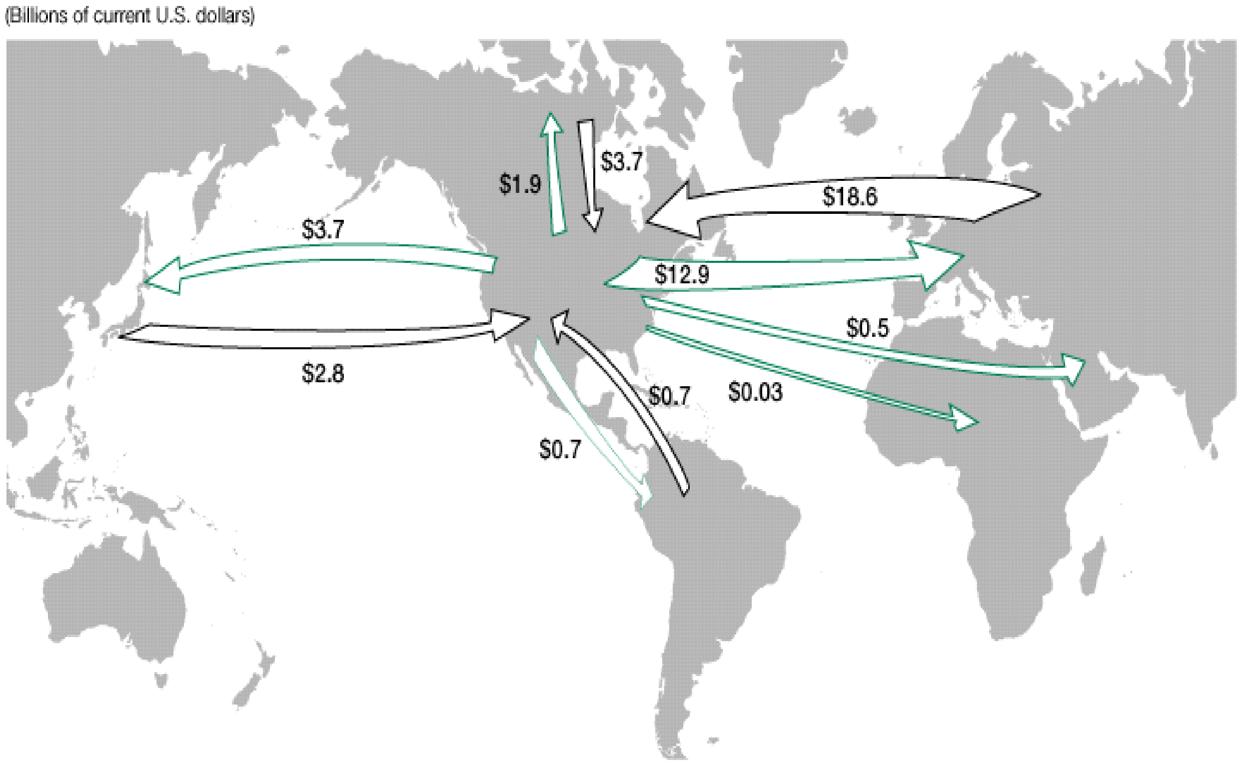
Note: Other sources include nonprofit, academic, and non-Federal government
Source:NSF Science Indicators 2004

Figure 5



Source: NSF Science Indicators 2004

Figure 6, Inbound and Outbound R&D Expenditures, U.S., 2002



Source: NSF Science Indicators 2004

Figure 7, Allocations of R&D Performed by Industry, 2002

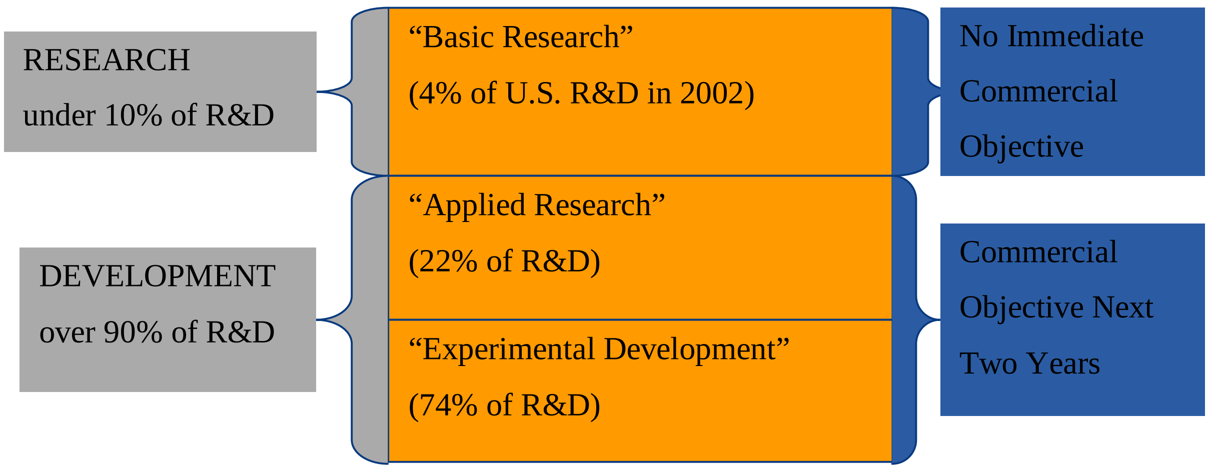
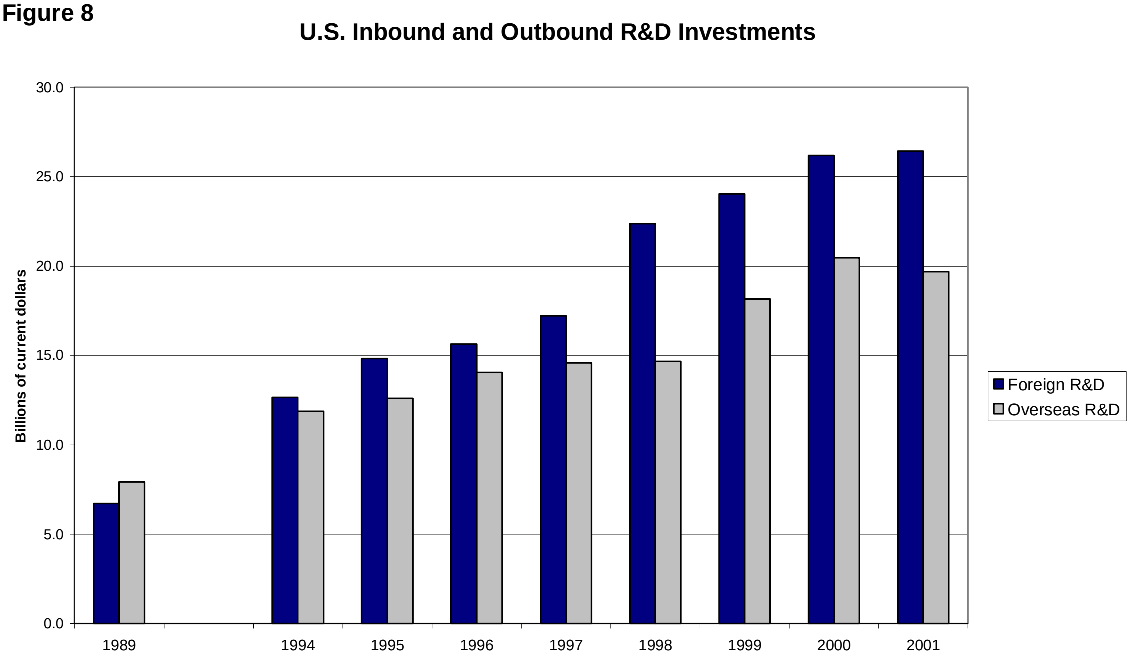


Figure 8



Note: Foreign R&D refers to R&D performed in the Untied States by U.S. affiliates of foreign parent companies. Overseas R&D performed abroad by foreign affiliates of U.S. parent companies.

Source: NSF Science Indicators 2004

Table 1
Share of Basic Research in Total R&D Performed by Business Enterprises

	1989	1995	2001
France	3.8	4.2	3.8
Germany	5.9	5.1	3.9
Japan	6.4	6.6	5.7
Netherlands	n/a	n/a	n/a
United Kingdom	4.7	4.3	4.2
United States	5.1	4.7	4.2

Source: OECD Science and Technology Database 2003

Table 2
Cost Structure of R&D from Firm Interviews

Input	Research	Development
Labor	60%	43%
Materials	15%	31%
Other current	20%	21%
Capital	5%	5%
Total	100%	100%

Source: TCB R&D Survey

Table 3
Industrial R&D Financed by Foreign Sources, 1989-2001

	Canada	*France*	*Germany*	*Italy*	*Netherlands*	*United Kingdom*	*Japan*	*European Union*
1989	17.1	10.9	2.7	6.5	3.9	13.4	0.1	7.6
1995	19.4	11.1	2.2	8.2	13.2	19.1	0.1	8.7
1996	20.7	11.4	2.2	9.6	9.8	21.7	0.1	9.2
1997	19.9	10.6	2.8	9.0	18.8	18.8	0.4	9.1
1998	26.0	9.4	2.7	8.1	14.5	22.1	0.4	9.1
1999	27.0	8.8	2.1	8.1	15.1	22.7	0.5	8.9
2000	27.0	9.0	2.1	8.2	15.4	21.5	0.6	8.7
2001	27.0	8.7	2.1	7.4	14.4	24.4	0.5	9.3

Source: OECD, Main Science and Technology Indicators, 2004.
Note: Data not available for U.S.

Table 4
Foreign affiliate R&D in the U.S.*

Country of Location	1989		1995		2000	
Canada	538	8%	1,337	9%	3,664	14%
Europe	5,414	81%	11,442	77%	18,610	71%
France	510	8%	1,529	10%	2,135	8%
Germany	1,216	18%	3,563	24%	5,610	22%
Netherlands	690	10%	786	5%	1,366	5%
U.K.	1,568	23%	2,316	16%	5,018	19%
Switzerland	1,060	16%	2,490	17%	3,013	12%
Asia and Pacific Countries	412	6%	1,611	11%	2,840	11%
Japan	369	5%	1,259	8%	2,617	10%
Other Countries	362	5%	389	3%	735	3%
Total Foreign R&D in United States	6,720	100%	14,846	100%	26,089	100%
Total U.S. Business R&D	625	9%	1,975	13%	3,835	15%

Source: NSF Science Indicators 2004
*Foreign affiliate R&D in the U.S. (millions of $) refers to R&D performed in the United States by U.S. affiliates of foreign parent companies

Table 5
Foreign R&D by U.S. affiliates*

Country of Location	1989		1995		2000	
Canada	975	12%	1,068	8%	1,874	9%
Europe	5,475	69%	9,144	73%	12,938	65%
France	521	7%	1,271	10%	1,445	7%
Germany	1,726	22%	3,068	24%	3,105	16%
Netherlands	367	5%	495	4%	369	2%
U.K.	1,718	22%	1,935	15%	4,000	20%
Switzerland	59	1%	242	2%	220	1%
Other Asian and Pacific Countries	1272	16%	1865	15%	3,727	19%
Japan	1000	13%	1286	10%	1433	7%
Australia	190	2%	287	2%	330	2%
Singapore	24	0%	63	1%	548	3%
Other Countries	199	3%	505	4%	1,219	6%
Total R&D Abroad	7,922	100%	12,582	100%	19,758	100%

Source: NSF Science Indicators 2004
* U.S. Foreign Affiliates' R&D Investment(millions of $) refers to R&D performed abroad by foreign affiliates of U.S. parent companies.

Table 6
Shares and growth of research and development expenditures by business enterprises and GDP

	Basic research by business			Development by business			GDP		
	1989	1995	2001	1989	1995	2001	1989	1995	2001
Current expenditure (mln US$)	11770	13772	16687	204151	252343	352366	11287361	14911436	18818765
Share in current expenditure									
France	5.2	6.3	5.9	7.7	7.8	7.0	8.7	8.1	8.1
Germany	11.0	9.6	8.1	10.0	9.8	9.5	11.5	12.4	11.3
Japan	34.1	34.7	30.2	28.9	26.6	23.4	22.3	20.6	16.6
Netherlands	n/a	n/a	n/a	n/a	n/a	n/a	2.3	2.3	2.6
United Kingdom	5.1	4.8	5.1	5.9	5.8	5.6	7.0	7.4	8.1
United States	44.5	44.6	50.6	47.4	49.9	54.5	48.2	49.2	53.4
Real expenditure (mln US$)	13531	13772	15857	235722	252343	331360	13770019	15585161	18323348
		1989-1995	1995-2001		1989-1995	1995-2001		1989-1995	1995-2001
Real growth (%)		1.8	14.1		6.8	27.2		2.1	2.7

Notes: Shares are calculated based on current research, current development expenditure and current GDP. Research expenditure and development expenditure in national currency is from the OECD Science and Technology database (2003). Expenditure is converted to U.S. dollars using the 1997 R&D PPP for total manufacturing (see Dougherty et al., 2004). Real research expenditure is calculated using the implicit GDP deflators from the OECD National Accounts database. GDP is converted to U.S. dollars using 1999 PPPs from OECD (2002).

Table 7
Share of basic research in R&D by country

	Performed by business			Performed by all sectors		
	1989	1995	2001	1989	1995	2001
France	3.8	4.2	3.8	20.3	22.2	23.3
Germany	5.9	5.1	3.9	19.6	n/a	n/a
Japan	6.4	6.6	5.7	12.3	14.2	12.2
Netherlands	14.5	n/a	n/a	15.1	9.6	n/a
United Kingdom	4.7	4.3	4.2	n/a	n/a	n/a
United States	5.1	4.7	4.2	15.4	16.1	17.2

Source: OECD Science and Technology Database (2003)

Table 8
Growth in research and development by sector and the share of business enterprises

	Basic research			Development			R&D		
Real growth (%)									
	1989-1995	1995-2001	Difference	1989-1995	1995-2001	Difference	1989-1995	1995-2001	Difference
France									
Business enterprise	6.7	-0.8	-7.5	2.7	2.8	0.1	2.9	2.7	-0.3
Other (government, education, non-profit)	3.6	2.8	-0.7	1.5	-0.7	-2.2	2.5	1.1	-1.4
Japan									
Business enterprise	1.4	-0.5	-1.9	1.2	2.5	1.3	1.2	2.3	1.1
Other (government, education, non-profit)	4.0	-0.7	-4.7	4.8	-5.8	-10.6	4.6	-4.4	-9.0
United States									
Business enterprise	1.7	4.2	2.5	3.4	6.0	2.5	3.4	5.9	2.5
Other (government, education, non-profit)	4.8	7.1	2.3	2.2	2.8	0.6	3.3	4.9	1.6
Business enterprise share (%)									
	1989	1995	2001	1989	1995	2001	1989	1995	2001
France	11	13	11	73	74	78	60	61	63
Japan	36	33	33	74	70	79	70	65	74
United States	24	21	18	81	82	84	72	72	73

Note: Similar breakdowns are not available to the same extent for Germany, Netherlands and U.K. Real growth is calculated as the growth in nominal expenditure minus the growth in the GDP deflator. Business enterprise share is calculated using current expe

Source: OECD Science and Technology database (2003, France, Japan), NSF Science and Engineering Indicators 2004 (United States)