28 Feb 2003

Internationalization and the Changing Structure of Business R&D: Recent Trends and Measurement Implications[1]

Sean M. Dougherty, Robert Inklaar, Robert H. McGuckin, Bart Van Ark
The Conference Board and Growth and Development Center of the University of Groningen

(First Draft, February 2003)

1. Introduction

Concerns with science and technology (S&T) capabilities are widespread 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. In particular, research and development (R&D) intensity – country and regional differences in S&T effort as measured by the proportion of income devoted to R&D – is a key focus of policy discussions across the world.[2] But the issues involve much more than aggregate intensity measures.

The productivity and composition of the R&D expenditures themselves vary from country-to-country and firm-to-firm and the motivations for undertaking R&D and the factors governing its location are not well understood. Since most of the R&D is undertaken in the private sector this is of particular concern to policy makers.

Unfortunately, information on the composition and distribution of R&D is limited. There are many reasons for this, but a major factor is the recent globalization of R&D. Globalization of R&D is one of the major developments of the 1990s and it is closely linked to increases in the

---

[1] The National Science Foundation project "Internationally Comparable Science, Technology, and Competitiveness Indicators" (SRS00-99594) supports this work.

[2] In Europe, for example, governments at the Barcelona European Council recently set targets that would increase R&D spending dramatically from 1.9% of GDP to 3.0% by 2010.

proportion of R&D financed by private business (NSB, 2002). Globalization and the rise of multinational companies are major factors in the renewed interest of the OECD in the creation of S&T indicators (OECD, 2001).

Even within countries, globalization of R&D programs has increased the complexity of analyzing technology capabilities and effort. A constant flow of workshops, panels, and commissions in the U.S. has called for improvements in the data collection system.[3]

Most reported data on the composition and distribution of R&D are highly aggregated. R&D expenditures are generally collected at company levels and there is limited information at the industry level, especially internationally, and virtually no information on the patterns of expenditures within large firms that undertake the majority of the R&D expenditures. Most of these large firms are multinational companies that are diversified across industries and between the "R" and "D" portions of R&D.[4] Moreover, there is strong evidence that the composition and organization of R&D is changing rapidly, making it particularly difficult to interpret trends in the aggregate data.

The current problems with the data echo concerns raised by Zvi Griliches 20 years ago on the occasion of the 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.[5]

This study seeks to address these deficits and understand the pattern of R&D activity internationally. We use information from 25 in-depth interviews with large multinational R&D performers in four high-tech industries to shed light on the composition of R&D activities within

---

[3] In fact a new panel has just been formed (1/2003) by NAS to address how the Science Resources Studies Division of the National Science Foundation can improve its data collection system for R&D.

[4] Concern about declines in the share of research in R&D has been repeated over many decades (Nelson, 1959; Link, 1985). More recently, concern about decreasing government support for basic research in industry has been made a major issue (NAS, 1999).

[5] Ten years later he broadened his attack in his presidential address to the American Economic Association, which provided a broad condemnation of the state of economic data, with particular focus on R&D and the service industries. In particular, Griliches noted that "[g]reat advances in…theory and econometric techniques…will be wasted unless they are applied to the right data."

the firm, how they are structured, and how they are changing. We study how the production of research and development differ, focusing on the relative uncertainty of research output compared with development. Moreover the costs (the "production function") of conducting each are quite different. These differences have broad implications for allocations of resources. In turn they help explain recent trends, including research becoming more concentrated in the U.S. and development of commercial products more dispersed worldwide.

We also utilize information collected by statistical agencies in conjunction with new experimental purchasing power parities (PPPs) for R&D spending for six major industrial countries – France, Germany, Japan, The Netherlands, United Kingdom and United States – and 13 manufacturing industries (Dougherty et al., 2002). These new measures and the interviews are used to describe how the global composition of R&D is changing, what factors are driving the changes, and how they are likely to evolve.

This paper proceeds as follows. In Section 2 we discuss definitions of R&D and describe how R differs from D. A variety of definitions used in practice and there are many possibilities for confusion on the part of respondents and analysts. We then examine why the distinction between R and D is important analytically and describe an economically useful way to look at the differences. The discussion then links R and D, as defined, to various organizational changes underway internationally. Section 3 briefly describes our sample of interviewed multinational firms and the international structure of their activities.

We turn to international comparisons of R&D costs based on published data and the new PPPs in Section 4. We look at how R&D costs change over the 1987 to 1997 period. These data are compared and interpreted in light of the estimates that we obtained from R&D managers. Comparisons of global flows of R&D and changes in costs follow. In Section 5 we separate the flows of research and development. In the final section (to be added) we summarize and discuss the overall results.

2. The R&D Process; Framing Conceptual Distinctions

In this section we spell out the essential elements of the R&D process as reflected in our interviews and the literature. In laying out this framework, we recognize that it is a simplified version of real world processes. Instead of dealing with the many phases of research and development activities we simply focus on two, research and development. While this ignores some interesting aspects of the process, it highlights important differences in the demands for R and D, for which outputs are notoriously difficult to measure.[6] We also describe differences in the production functions that govern each.

Many of these differences between research and development have been identified in earlier work. But their relevance has become more important in firm organizational and location decisions. Rapid development of information and communications technology and lower transportation costs, and the increased competition that has accompanied them, are playing major roles in the organization of R&D activities. And these differences are key factors in the observed patterns of globalization.[7]

2.1 Distinguishing Research from Development

There is a long literature dealing with the distinctions between research and development. While many definitions have been put forward, most – including those used in current national and international statistical programs – distinguish between three types of R&D activity: basic research, applied research, and development.

---

[6] Recent studies suggest that early and latter stages of development are very different and that several stages of research can be usefully distinguished.

[7] Aside from geographic location, there is also great variation among firms in how they organize and produce R&D. For example, some firms simply buy research on the open market and there is an emerging trend toward specialized research firms, which do nothing but contract research work for other firms.

"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 of these 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 the terminology varies, such definitions have been used since Vannevar Bush's seminal work on R&D taxonomies in 1945. In our interviews most R&D managers felt the definitions were clear and conceptually appropriate. Yet most also felt that they didn't adequately convey the complexity of the process. More important, they thought that even though the categories could be distinguished in theory, they found it hard to draw lines in practice.

Most 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. But they did do a fair amount of research that sought new knowledge in areas of their business operations, even though the exact commercial processes and products that were going to emerge from the process were uncertain.

If most research performed in industry is oriented toward a current or future field of potential commercial interest, then most business R&D falls in the applied research and development categories based on the Frascati definitions. 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 fact it is extremely unlikely that 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. There is still some fundamental work going on in companies where large government contracts depend on matching expenditures or fundamental work is contracted for by the government. But business research generally seeks to fill a business need.[8]

This fact was recognized by Link (1996), who distinguishes basic or fundamental research from applied research by whether a specific application for the research has been determined. The U.S. National Science Foundation now uses a similar distinction: "research projects that advance scientific knowledge but do[es] not have specific immediate commercial objectives" (NSB, 2002). Indeed a close reading of the Frascati manual and its references to a subset of basic research that is "oriented" suggests that a similar interpretation is meant: work done in a field of current or potential business interest (but does not yet have a practical application). But national practices vary somewhat and it is difficult in practice to know what is reported.[9] For instance, the Statistics Bureau of Japan defines basic research as "research undertaken primarily for the advancement of scientific knowledge, where a specific practical objective is indirectly sought" (SBJ, 2002).

Practitioner's Views

R&D managers usually distinguish basic and applied research by whether the research has a specific *commercial objective*. If the expected results of the research are uncertain as to its commercial objective, it is basic; if it is targeted toward a specific commercial objective, it is applied research. Both basic and applied research is directed toward discovering new knowledge.

Viewed in this way our survey results are pretty much in line with Link (1996) who found that companies generally affirmed the appropriateness of the categories, but found precise

---

[8] Some managers suggested that such basic research was supported in the past, but budgets left little room for research that didn't support the business plan. Typically "fundamental" work was undertaken in universities or small firms linked to them. Government laboratories were also cited as a source of this kind of work. Moreover, where more basic research was necessary, firms looked to university related partnerships and alliances for help.

[9] Reporting for national surveys is usually done by the accounting function with little input from R&D managers.

lines between them difficult to draw. Basic and applied research, as defined here, appears to meet the original knowledge requirements for the pre-2001 U.S. Research and Experimentation (R&E) tax credits.[10] However, business found it difficult to prove that knowledge was original – essentially the distinction between applied research and development – and a new standard was adopted in December 2001. It only requires that R&D be technological in nature. This emphasizes the difficulties business has in consistently reporting various types of research in surveys.

Nonetheless, it is clear that research work is more applied as it gets closer to commercial development. In fact, R&D executives use the term early stage technical development (ESTD) to describe the more applied parts of the process (Branscomb and Auerswald, 2002). While there are legitimate distinctions between research categories, applied research may be more appropriately classified in the development part of the R&D taxonomy.[11]

2.2 Economic Distinctions between R&D

Aside from practical considerations, the definitions don't make the most economically relevant distinctions. In particular the uncertainty associated with research is much different than that associated with development. Moreover, the time horizons, labor and capital inputs, and the within-firm organization are very different for research and development.

Research Outputs are Uncertain

Nelson (1959) emphasized the importance of uncertainty in distinguishing R from D: The degree of uncertainty in the ex ante results of research versus development was much greater for research. IT is also clear that the uncertainty is across very different states of nature for R and D. Development involves clearly defined commercial projects for the firm itself, while R involves a range of potential business and commercial objectives both within and outside the firm.

Nelson is surely right in focusing on the uncertainty of the results of research. Aside from the possibility that the research effort fails to find anything new, the research may not

---

[10] A Basic Research tax credit applies to work that is contracted out to educational institutions and approved scientific organizations.

[11] Link found firms expressed more difficulty making distinctions between development and engineering.

generate a commercially viable product.[12] In addition, and of great importance, the research results may not fit well within the firm's business plans. Thus, there is often great uncertainty about the relevance of research to business objectives.

Even if you get a commercially viable product, if it does not fit with your 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 doesn't fit the firm's business plan, then either another firm must be found for the development and marketing or the firm must adjust their business plans. Neither option is easy as stressed by many of the R&D managers we spoke with.

From these observations 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. Indeed one of the key issues for business today is how to obtain value from research that does not fit neatly into the firm's business plans.

Development Output is Well-defined

Development involves the improvement of existing products and processes and the creation of new ones. R&D managers generally distinguish it on the basis that it involves a specific new commercial application. Output and often the scale of required resources are known at the outset with development. This means that the level of technical risk for development projects is considerably lower than that for research.[13] Moreover, development is more focused on specific commercial objectives with relatively short time horizons. In contrast, research lacks a well-defined commercial application and involves a high level of technical uncertainty, longer time horizons to realization, and more uncertain resource requirements.

---

[12] Finding that some avenue or path is a dead-end is useful knowledge in assessing future research and so one could argue there are no real failures. But failure to find knowledge with direct links to new products or processes represents a commercial failure to the firm.

[13] Still, market risk, especially from obsolescence or being scooped by a competitor, is a major concern.

Research is focused on advancing scientific knowledge and exploring new technologies before the goals have been clarified to the point of determining a specific practical application. Whether or not the work is based on new or existing knowledge (or less or greater proportions of new and old) was not a distinction raised by the R&D managers. But, late stage research or early stage development is very applied in the sense that it involves 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? Thus, development, while entailing risk, exhibits much less uncertainty with respect to its output than research.

Production of Research and Development

Research and development production processes vary considerably across fields of science and industries of application. But there appear to be some general considerations that apply to each activity. Virtually every interview indicated that research involves a much higher proportion of high skilled Ph.D. scientists than development. Thus, labor expense is much greater for research, as shown in Table 1a.[14]

While the use of materials and capital varies across fields of science, it also appears that development uses more materials than research. Materials are one of the biggest components of the "other" category. This finding comes from a small sample of firms that provided more details on the other category.

These differences appear to be widespread across industries and countries: differences in firm cost shares from country/industry averages derived from national R&D surveys were near zero for development, but substantial for research, as shown in Table 1b. The average for the universe of firms reported by the R&D surveys will mostly reflect D since development makes up most of the reported R&D totals**.** Thus, the near-zero deviations for the firm cost shares in the development are expected. However, the deviations of the firm cost shares for research are substantial. While quantitative firm/industry/country industry data are limited, they support the

[14] Note that if production is organized along Cobb-Douglas lines, then the cost shares reflect production elasticities.

argument that the inputs to the production of research tend to differ significantly from development.

Neither research nor development operates totally independently. Typically, 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. But, internal transfer of technology is often described as quite difficult. 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 every firm we interviewed indicated that it had recently undergone major changes in the organization and structure of its R&D activities. In particular, nearly half the firms said that their divisional structure was radically different as little as two years ago.

Firms are actively creating organizational structures that specialize in R and D yet have fluid interactions. Many executives described the changes as movements toward globally integrated “matrix management,” where labs and development functions are consolidated globally across business units; mergers are often a driver of these changes.[15] 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 (Beise and Belitz, 1998; Branstetter and Nakamura, 2003).

2.3 Organization of R&D within the Firm

The structure of the R&D process is illustrated in Figure 1. There are various ways to organize the flow from research to development and production and marketing. Increasingly the steps in the process are being located outside the firm’s primary research unit, particularly in the

[15] Multinationals headquartered in the United States and Europe seemed to be much further along in these reorganizations than Japanese firms. Indeed, a recent paper suggests that the Japanese are following the “American” organization model.

operations areas of the firm.[16] In turn, most firms said that resources in the primary research units were reduced. This is consistent with a chorus of concerns about the R&D from within and outside the government.

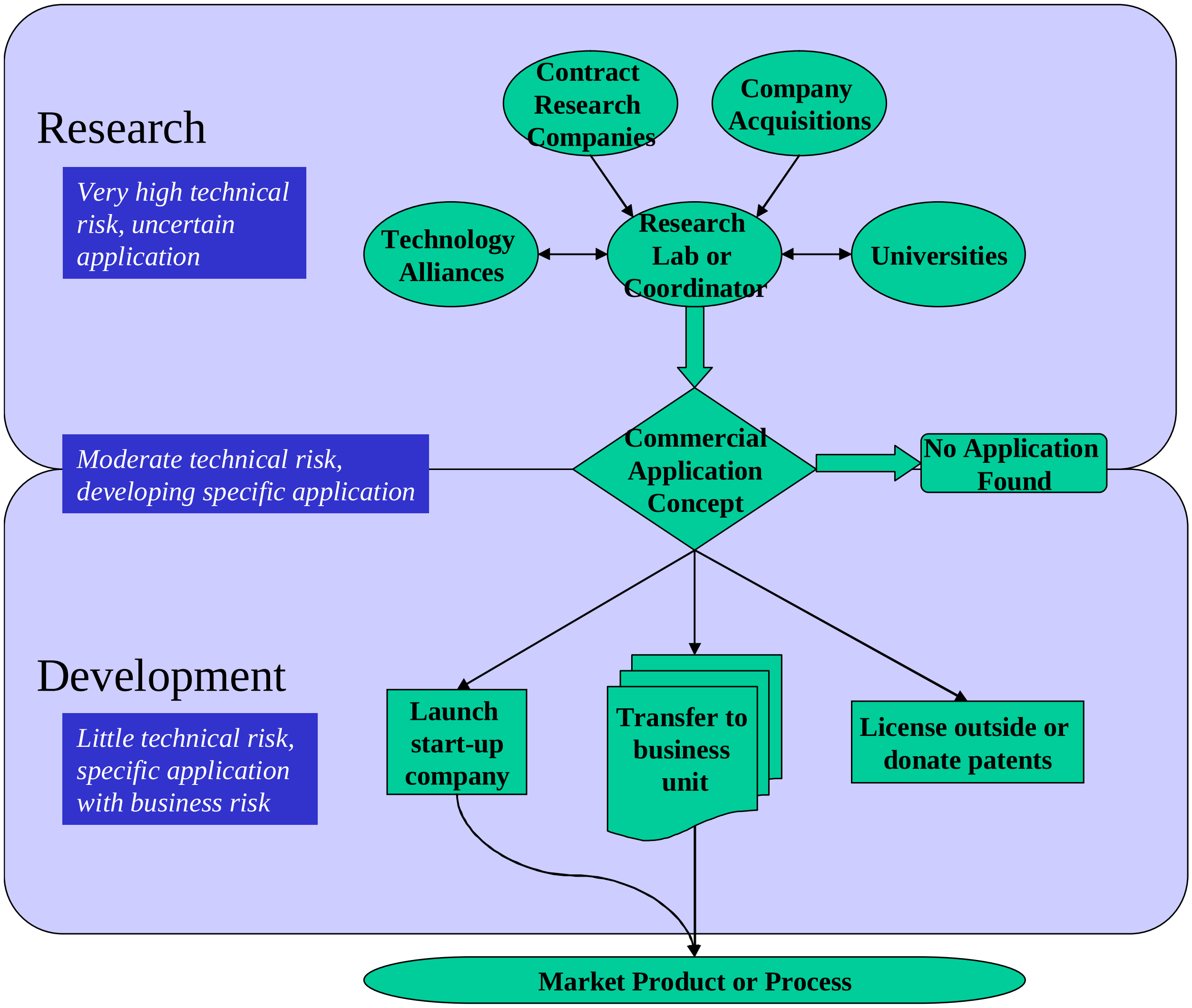
What is Diving Organizational change?

One factor in these changes is specialization of function: Business has sought to focus R&D resources in organizational units 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.

[16] There has also been increased outsourcing of research functions, but we leave that aspect of the process for now since most of are evidence is anecdotal.

FIGURE 1

Schematic of the Organization of R and D



Sources: firm interviews and cited literature

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. Our 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.

A third factor in the shift of R&D resources to the business unit is new management practices. 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. For instance, a research group may be global in its organization, while individual group members also have responsibility to their geographically associated business unit. This type of structure 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).

In the new matrix organizations, R&D is not usually a fully consolidated function. For those firms that have research laboratories, the heads of the labs typical report directly to the CEO (and less frequently to the CTO), while development is part of business units and executives there report to business unit Presidents. Thus, specific individuals are not responsible for both research and development. Nonetheless, enabled by widespread declines in transportation and communication costs driven by information technology, matrix management makes it possible for companies to integrate their R and D and operational activities.

Outsourcing and Alliances

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. 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.

As shown in Figure 1, the sources of inputs to the development of new products involve alliances and contracting with many outside organizations. Universities are the prime organization in this regard (Mansfield, 1995). Nearly all of the firms we interviewed are heavily involved with universities and consider them a vital part of their R&D work, especially for research. Moreover, many firms' international investments are motivated by a desire to work closely with particular universities.

The importance of work with universities, however, is much greater than the expenditures that are involved would indicate. No firm devotes a large share of their R&D budget to these activities, despite their perceived importance. Instead, a substantial proportion of their interactions come directly through individual professors and their links to scientists at the firm (Zucker and Darby, 1995).

Universities are increasingly patenting and licensing their research and focusing on commercialization (Mowrey et. al., 2001; Adams, 2002). Policymakers have worried that the increase in the commercial orientation of universities will lead to a drain on basic research. Some recent evidence suggests these worries are overdrawn as both basic and applied R&D in universities has grown in tandem (Cohen et al., 2002).

While we have not developed systematic survey information, there is also a clear tendency for research to be done by outside firms. For example, dedicated "research" firms specializing in research in particular areas of science and technology are expanding. Increasingly, dedicated R&D firms are being relied upon to offer their clients cutting-edge technology. And suppliers are often the primary location for R&D for firms, particularly those with complex structures. For example, supply firms specializing in locks can often spread the costs of research on safety and performance across competitive firms that use their locks as inputs. In both cases there are opportunities in the form of "spillovers" from a firm's work with the client's competitors. Even in the cases of those firms that do much of their R&D in-house, many make use of outside companies for specific tasks in areas that are outside their areas of expertise or require special equipment. In addition, firms obtain new technologies, applications and potential applications from small firms through acquisition or licensing. Many of these small firms are tied to universities.

Geographic Structure of R&D

Research is far less dispersed than development within and outside the firm's headquarters country. Many companies emphasized the importance of close cooperation and collaboration in their research groups, and sought to concentrate most research projects geographically.[17] Thus, research is usually concentrated in the home country. When research is done outside of the home country, it is motivated by a desire to work more closely with experts in a particular field at specific locations. Such research usually involves a university or technology alliance with another firm. These efforts are generally quite small in scale, and range from funding for a specific research project to a small laboratory near the university. Instances of significant "overseas" research are primarily associated with the integration and maintenance of activities that are acquired in mergers.

---

[17] Some executives even identified differences in time zone as a major obstacle to regular interaction in their research work, notably in contrast to the stories of 24/7 global syncopation in more predictable endeavors.

Development is much more disbursed, with companies having development activities in many locations and a substantial global presence. The driving force for most development is the destination market. Factors include proximity to customers, suppliers, and manufacturing facilities, as well as satisfaction of regulatory requirements. For example, for auto manufacturing, car models are developed in each major market to respond to local preferences, take advantage of local suppliers, and utilize regional manufacturing facilities. For pharmaceuticals, there are many country-specific regulatory requirements, unique health care practices, and varying availability of participants for clinical trials. For telecom and computers, different regions have different communications standards, needs for unique language interfaces, and varying receptivity to new devices.

The literature on R&D is very large and is reviewed as part of our larger report (in process). However, we discuss two recent studies that are close in approach to ours: Each develops 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., Japan, and Asian Tigers. 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, distinguishing between home base exploiting (HBE) R&D units, which transfer the firm's existing technology overseas, and home base augmenting (HBA) units, which create new scientific knowledge using host country resources. These categories are in many ways comparable to research (HBA) and development (HBE).[18]

These 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. They both emphasize the existence of complementary inputs in the location

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

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.

In all of our interviews, the role of *cost* was not considered to be a major factor in location decisions, particularly for research. It wasn't that costs were ignored, but executives felt that cost frequently was dominated by other considerations. Nevertheless, costs inevitably affect profitability and rates of return and it remains to be seen whether patterns of location changes are related to costs of operating in particular areas as well as the more specific motivations identified above.

3. Interviewed Companies

This paper utilizes the results of interviews with R&D executives at 25 large multinational firms in the U.S., E.U, and Japan in the pharmaceuticals, office and computing machinery, telecommunications equipment, and motor vehicles industries to guide the interpretation and utilization of international R&D statistics. (The interviewing process is ongoing.) These interviews involve one to two hour in-person on-site meetings, followed by a follow-up survey of detailed financial information on R&D costs and expenditure. Information on the organization, scope, definition, location, and reporting practices of R&D were discussed.

3.1 Selection Criteria

Firms were selected based on the similarity of their R&D intensity to the median firm intensity in its home country and industry, based on the *Compustat Global* database of public companies (Standard and Poor’s, 2002). R&D intensities were also compared with industry averages in each country’s national R&D surveys. Since the firms were in many cases quite large, our coverage of many industries is substantial and in some cases overwhelming. This suggests that information we draw from on the firm interviews directly reflect the business conditions in a sizable part of each industry.

3.2 Profiles of companies

We interviewed 5 firms in the Pharmaceuticals industry, 7 firms in Computers, 6 firms in Telecom, and 5 firms in Motor Vehicles, as shown in Table 2. In addition, we interviewed several additional companies (not shown) in related industries, including dedicated R&D services, Chemicals, and Petroleum. All of the selected companies perform a large amount of R&D, with expenditures ranging from 3.5% to 21% of sales.

The R&D intensities of the sampled firms are similar to the industry-wide intensities on average. However, the spread between the firms and the industry intensities can be quite large. This reflects the great heterogeneity among firms, even in the same industry. But the spread also reflects the procedures used to pick the firms we interviewed. For example, in the telecom industry, (publicly traded) U.S. firms in *Compustat* show R&D intensities nearly twice as large as those reported in the NSF R&D Survey. Thus, in the Telecom industry, we appear to be sampling from the higher end of the R&D intensity distribution. In the Computer industry, we probably have more firms in the lower half of the distribution.

Still, the firms are rarely outside the range of the industry-wide or average intensities. Especially in the pharmaceutical and motor vehicle industries, our selected firms have R&D intensities close to industry levels. These results hold across the U.S. and Japan (and in the European countries we have covered so far). Moreover, our coverage of total R&D performed in an industry is often substantial for a country. This suggests that conclusions we draw from the firm interviews should reflect a sizable part of each industry and are broadly representative of larger multinational firms in each industry.[19]

3.3 International Structure

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.

The internationalization of the computer and telecommunications firms varied quite a lot depending on where they were based. Computer firms were clustered primarily around Silicon Valley, while telecom firms were more in the Tri-State (NJ/NJ/PA) area. The U.S.-based companies sell more than half of their products abroad, while Japanese-based companies sell more than two-thirds of their products domestically. Restructuring in this industry has actually led to the reverse internationalization (consolidation) of some production facilities as this work

---

[19] A copy of the survey instrument, a list of companies and summary information from public sources are available on request. Since confidentiality was a key promise, the individual responses will not be disclosed.

has increasingly been outsourced to overseas manufacturers. R&D facilities for these companies were heavily concentrated in home markets, although some companies, such as IBM, do have research facilities in multiple locations, and sell products in many different international markets (according to their website).

Companies in the motor vehicles industry are heavily focused on major developed country markets of the U.S., Japan, and Europe. Sales to other countries represent a small share of their sales, and the location of their production reflects this, given the high transportation costs for cars. Motor vehicle firms maintain large technical facilities not only at home but also in each of the major developed markets.

4. International R&D and Cost

In this section we examine differences in the cost of R&D across countries. We also develop estimates of differences by industry. These estimates are based on published survey data and PPP estimates from our earlier work (Dougherty et al., 2002). The R&D cost measures are developed for both 1987 and 1997, enabling us to look at trends. In addition we have some limited information from our company interviews of R&D managers' estimates of the relative costs of undertaking R&D internationally. These are used to assess the cost estimates from the published data.

We also undertake similar exercises, but for the international distribution of R&D expenditures. We look at the distributions again for 1987 and 1997 to measure the long-term international flows of R&D. These data are developed for both U.S. and foreign based companies. Finally, we make some simple comparisons of the flows with the changes in costs on a country-by-country basis.

4.1 International Comparisons of R&D Costs

Comparisons of the cost of doing R&D in different countries require purchasing power parity (PPP) measures to convert cost figures in local currency to comparable quantities. We begin with a brief overview of our procedures. They were applied to 13 manufacturing industries (branches) branch of manufacturing in six countries, U.S., U.K., France, Japan, and Germany and The Netherlands. The measures we develop depart substantially from both of their common substitutes, GDP PPPs and market exchange rates.

R&D PPPs

Our R&D-specific PPPs are based on the industry-of-origin methods in van Ark (1993) and van Ark and Timmer (2001). We also employ the expenditure approach in Kravis et al. (1982) and Heston and Summers (1996) where appropriate. The data come from national R&D surveys and international price databases calibrated with firm interviews and accounting data. There are three basic steps: (*a*) Calculate industry-specific labor PPPs using R&D survey data, using information about the composition of researchers and support personnel from interviews;

(*b*) compile PPPs for other current and capital expenditure using industrial census and consumer-producer price data for expenditure items selected on the basis of the interviews; (*c*) use industry-specific R&D cost shares to aggregate these separate PPPs to form Fisher-type R&D PPPs.

For the country level aggregation, cost weights of the base country – the United States – are used to create a Laspeyres PPP,

$$PPP_L^{x,u} = \sum_i w_i^u PPP_i \qquad (1)$$

Equation (1) is simply a share-weighted average of the individual PPPs for three cost categories, labor, other costs and capital expenditure, indexed by *i*. Cost shares are based on U.S. dollar expenditures:

$$w_i^u = C_i^u \Big/ \sum_j C_j^u \qquad (2)$$

where *i* and *j* index the cost categories. For the comparison country we use that country's cost weights to calculate a Paasche PPP,

$$PPP_P^{x,u} = \sum_i w_i^x PPP_i \qquad (3)$$

$$w_i^x = (C_i^x / PPP_i) \Big/ \sum_j (C_j^x / PPP_j) \qquad (4)$$

Where w_i^x is the cost share of cost category *i* in the other country (*x*) converted into U.S. dollars using the PPP. Taking a geometric average of (1) and (3) yields a Fisher PPP, our measure of cost of R&D in local currency units of country *x* per U.S. dollar.[20] Comparing these PPPs to exchange rates provides a measure of relative R&D costs compared to the U.S., which is the common base country in our work.

[20] We address the issue of changes in the quality of the R&D inputs with comparisons of industry-wide PPPs with Hedonic prices such as those in Danzon and Chao (2000) for pharmaceuticals. (See Dougherty et al. (2002) and Inklaar et al. (2002).)

Estimates from R&D Managers

The basic building blocks for the country-level R&D cost comparisons are the country-specific industry PPPs. To check the validity of our underlying estimates, we compared the implied cost differences from the PPP calculations for individual industries with direct estimates of relative R&D cost from a firm we interviewed in the same industry. The cost differences implied by the R&D PPPs for individual industries compare favorably with results from our interviews as shown in Table 3.

Because the number of firms in each industry is small, we simply label the industries one to four. Since we had comments from many of the firms on China, we included it in the Table, even though we don't have PPP estimates for it.[21] One clear pattern from the Table is that Japan and Germany were considered by firms to be the most expensive, and this is what our PPP results also tell us. The U.K. was generally considered inexpensive, but as with the PPP estimates for 1998, in two of the industries, costs were about the same as the U.S. The costs for France were much higher from the perspective of the firms, but this is for one industry only and our sample is particularly small. Overall, however, these comparisons seem to suggest that our R&D PPP estimates are plausible.

Country-level Differences in R&D Costs

The R&D PPPs allow us to calculate the relative cost of doing R&D in different countries. We estimate R&D PPPs for individual countries in two "benchmark" years, 1987 and 1997. These figures are shown in Table 4b. They represent the equivalent cost of performing comparable R&D in each country's currency units. Thus, they can be used like exchange rates for comparing R&D expenditures.

In order to look at changes in the relative cost of R&D across countries, we divide the R&D PPP by the exchange rate to calculate the price level of R&D in each country relative to the United States. And since we look at changes across time, we also interpolate these R&D PPPs for two other years, 1995 and 1998, using the GDP deflator for these non-benchmark years.

---

[21] China was described as least expensive in all cases.

The GDP deflator has been shown (in the U.S.) to be a reasonable proxy for the R&D deflator for inter-temporal comparisons at the country level. Differences between R&D deflators and the GDP deflator that exist at the industry level are averaged out, yielding a reasonable approximation to the true R&D deflator (Jankowski, 1993).[22]

The cost of R&D relative to the U.S. is shown for six countries in Table 3a. Based on these figures, the cost of performing R&D in France, Germany, Japan, and the Netherlands was comparable overall with the United States in 1987. The U.K. had much lower costs, an observation confirmed by several interviews. By 1997, the cost picture had changed dramatically. Costs outside the U.S. rose significantly over the 1990s for Germany and Japan. France and The Netherlands showed some declines in costs so they are roughly comparable to the U.S. While the U.K. still has somewhat lower costs than the U.S., the gap narrowed and by 1998, they were only 6% lower.

Differences in the costs for individual industries showed that costs varied significantly, but the variation was not as large as the variability across countries in either 1987 or 1997. This suggests that institutions and rules governing labor, capital, and product markets play a key role in determining costs. While the types of research undertaken are driven by the science and technology opportunities of the industry in which a firm operates, these factors appear somewhat less important than the institutions in the country.

4.2 The International Distribution of R&D

R&D has become significantly more internationalized over the past decade. Table 5 shows the proportions of total R&D expenditures that are accounted for by firms based outside the country where they are made. The table covers four countries and the E.U. as a whole yearly from 1987 to 1998.

The U.K. is by far the biggest recipient of foreign R&D investments, but its lead has been shrinking. Historically, Germany attracted very little foreign R&D and this did not change with the unification of the East and West in 1991. France has attracted roughly 10% of its total R&D

---

[22] Ideally, we would use R&D specific-deflators, which we hope to develop at the country and industry levels in the future.

from foreign sources throughout the period. Japan has virtually no overseas R&D expenditures by foreign firms.

In 1987 only 5% of U.S. R&D was derived from foreign companies. This proportion grew steadily, reaching 10% in 1994 and after a flat period in 1995 to 1997, it reached 13% in 1998. This movement from 5% to 13% represents a substantial compound annual growth rate of over 10%. In fact the growth of foreign R&D in the U.S. has substantially outpaced growth in domestic-owned R&D, even during the 1995 to 2000 period, when domestic R&D growth accelerated from less than 1% per year to over 6% per year (see Table 6). This much more rapid growth was achieved despite a deceleration in the growth of foreign R&D investment in the U.S. from 13 to 10 percent after 1995.

Sources and Directions of Foreign R&D: the U.S .Case

Table 7a shows the distribution of foreign R&D in the U.S. by country of origin. The information includes information on five countries and a rest of the world category. In 1998 Germany, the U.K. and Japan each have more than a 10 percent share of total foreign R&D in the U.S. France also has close to a 10% share.

Taken together these four countries account for about 60% of foreign R&D expenditures in the U.S. These same four countries accounted for only 46% of foreign R&D expenditures in 1987. Thus, their shares have grown substantially. Japan in particular has increased its share of U.S. expenditures by foreign companies, moving from about 3% in 1989 to 12% in 1998 The share represented by "other" countries decreased, as these larger countries have increased their shares. Aside from Japan and Germany, France increased slightly. But the U.K. and the Netherlands showed declines in their shares. The U.K. share of foreign R&D in the U.S. has declined slightly, but it remains large, at 17%. The Netherlands' share has declined sharply, to 4% from 12% in 1987.

R&D performed by U.S. companies overseas has followed different trends. First, the rate of growth of the total outbound expenditures has been much slower than the inbound. In fact, inbound R&D by foreign companies is substantially greater than outbound expenditures.

Second, U.S. companies' overseas R&D expenditures have become more dispersed across countries (see Table 7b). In each of the countries in our study, their respective share of overseas U.S. R&D has declined over the 1987 to 1998 period, while the share attributable to countries outside our study has grown.

4.3 Relationship between costs and flows of R&D

The trends in the internationalization of R&D just described identify several key developments. First, there has been a large increase in the foreign R&D performed in the U.S. and U.K. Second, German and Japanese companies increasingly do R&D outside their home country. Third, R&D performed abroad by U.S. multinationals has become increasingly dispersed outside the core group of large industrialized nations.

These developments mirror shifts in the relative costs of doing R&D in particular countries over the same period. For example, the countries with the highest costs (Germany and Japan) are the same countries that have invested the most in the U.S. over the past decade. Similarly, countries with the lowest costs (the U.S. and U.K.) have experienced the fastest rise in foreign-owned R&D.

In what follows we investigate this relationship between the costs and flows of R&D investment at the country level. Changes in the global allocations of R&D expenditure in internationally comparable units are compared with changes in the cost of R&D.

Country-level evidence

In order to examine country-level flows of R&D expenditure, we need first adjust current expenditures in local currency for changes in estimated R&D cost over time, and then convert these constant expenditures into common currency units with R&D PPPs. We use each country's GDP deflator to convert current local currency expenditures into constant expenditures, following the same rationale used in applying it to R&D Costs above. We then use the R&D PPPs shown in Table 4b to convert the local currency units into international U.S. dollars.

Table 8 shows the global distribution as represented by the R&D expenditures of the five large industrial countries in our sample. In compiling Table 8 we took the total R&D expenditures by the five countries listed in the Table and then calculated each country's share in each of the four years shown. (Recall that 1987 and 1997 are benchmarks. The years 1995 and 1998 are obtained through interpolation with national deflators.)

As suggested by the inflows and outflows of foreign R&D expenditures discussed above, there was a decisive shift in the global distribution of R&D expenditure toward the United States in the 1990s. U.S. expenditures on R&D were 41% of the total in 1987 and 53% in 1998. At the same time Germany and Japan's shares fell significantly. The shares of France and the U.K. remained relatively constant.

These patterns generally mirror those found for the costs. The U.S., with a substantial decline in relative costs, saw its expenditure shares increase dramatically. In fact it is the only country that experienced an overall increase. Both Japan and Germany experienced a large rise in the cost of performing R&D from 1987 to 1998, with Japan's share of global R&D decreasing from 30% to 24% and Germany's from 13% to 9% over the same period. In France where costs did not change very much over the last decade, the share of global R&D has remained relatively stable. The one anomaly is the U.K., which held its share at about the same level, despite a substantial increase in costs. On the other hand, the relative costs in the UK were still lower than other countries, even with the big increases in cost it experienced.

These comparisons, while illustrative and suggestive suffer because they don't control for other factors that will affect changes country R&D expenditures. While the overall expenditures as well as those in each country rose, the differential growth in the U.S. for example may simply reflect greater opportunities for R&D investments. For example, the U.S. growth rates over this period were much higher than Europe, particularly in the second half of the 1990s. Moreover, special situations in a particular country (e.g. the reunification of Germany) may affect expenditures in that country.

Industry-level evidence

(While we hope to add industry level analysis in the future this work must await a better resolution of what deflators to use for industry R&D expenditures. The industry analysis would allow for sharper distinctions since we would have enough observations to do some simple econometrics and we know, for example, just because Germany got more expensive overall, in some industries it became cheaper to undertake R&D.)

5. Global Flows of Research as Distinct from Development

Given the central importance of research, as distinct from development, in policy debates about R&D, this section looks at the global flows of each. We then examine how they relate to the expected flows based on the conceptual framework and the factors identified in our firm interviews supplemented by the results of other studies.

5.1 Distinguishing R and D in the data

A central difficulty in making comparisons of the components of R&D internationally is maintaining consistent definitions across countries, industries, and firms. In principle, R&D and the subcategories of basic research, applied research, and experimental development are clearly defined by the Frascati Manual (OECD, 1992, 2002) that guides national statistical authorities. But as we outlined in earlier sections many questions of interpretation arise in practice (i.e. Link, 1996), and systematic inconsistencies in reporting are observed even in reports of total R&D (Hall and Long, 1999). Our interviews confirmed the difficulty firms face in reporting R&D. Companies have a wide range of interpretations on the boundaries of research and development, and development from engineering, even within the same industry. These classification problems were common to firms in all countries.

Difficulties increased when companies were asked to apply the standard definitions of basic research, applied research, and (experimental) development to their expenditures. Most R&D managers felt basic research was relatively straightforward to distinguish from development because efforts to organizationally distinguish them were underway: A reasonable line could be drawn between whether or not a specific commercial application was the focus of the expenditure. Once a specific commercial application is determined, work is transferred to the most relevant business unit (see Figure 1). This line generally marked the beginning of the development stage. This separation coincides with the Frascati separation of basic and applied research.

While the organizational transformations that are moving development (or applied research) expenditures to business units are a relatively recent and ongoing phenomena, it appears that research is essentially basic research as reported in the published statistics and development is the sum of applied research and development. Firm interviews show that work done in corporate research laboratories, which typically perform work without a specific commercial application, almost never exceeds 10% of total R&D. At the same time, basic research in national statistics is on the order of 5% to 8% of total R&D. This suggests that a majority of what is done in corporate laboratories is basic research as reported in surveys. Moreover, since applied research in national statistics is in the 20% to 30% range, this suggests that most "applied research" (early stage technical development) is better viewed with development activities for purposes of international comparisons.

Based on this rationale we collapsed the three standard categories of R&D in the published data into just two: research and development. This categorization separates research from more applied activities and is more likely to be consistently reported than the three standard categories.

5.2 Global Flows of R and D

Table 9 shows the distributions of both research and development expenditure for our six countries for the years 1987 and 1997. Both research and development contributed to the already discussed growth in overall R&D expenditures. Two things stand out in the table. First, the U.S. increased its shares of both R and D. All other countries declined, with France just maintaining its share of research. Second, the increase in research expenditures was particularly fast after 1995.

Changes in development expenditure over the period 1987 to 1998 (Table 9b) closely resemble those for R&D as a whole (Table 8). This is not surprising given that development accounts for roughly 90% of the total. The research flows are quite similar in direction, but the changes are bigger.

There was a dramatic increase in the global share of research performed in the U.S., from 42% in 1987 to 64% in 1998 (Table 9a). Much of the growth of basic research in the U.S. occurred in the latter half of the 1990s. Indeed, U.S. research grew by 20% annually since 1995, far outpacing the 6.1% annual growth of development (Table 10).

At the same time, Japan's research share declined from 35% to only 20%, and Germany's dropped from 11% to 7%. These changes are in the same directions indicated by costs, but they are much more pronounced shifts than those observed for development. Furthermore, the decline in the share of basic research in the U.K. is hard to explain since while costs rose, they were still cheaper than other countries, including the U.S. This suggests other factors may be at work.

Table 11 shows the shares of total R&D funded by business that are used for research in each country. Viewed as a part of total R&D expenditures, the U.S. was in about the middle of a very even distribution of research expenditures as late as 1995. That is in most countries it appears that mix between research and development in the total research pie was similar. In the intervening years, however, the U.S. increased its research proportion rapidly and it had by far the largest percentage of R&D going to R: about 8%, compared to percentages of 4.4 in France and 5.6% in Japan in 1998.

5.3 Why has Research Grown so Much in the United States?

There has been a decisive increase in the U.S. share of global research. This is a potentially important development and it takes place in an environment where research and development expenditures have been growing rapidly. While costs appear to be part of the explanation, there also appear to be other factors at work.

Earlier we identified proximity to centers of science and technology excellence and the location of existing research activities and company headquarters as the main factors in the geographic allocation of research. Of course opportunities for scientific breakthroughs and commercial possibilities are primary determinants of the level of effort. In addition, firms suggested that cost plays a more substantial effect on allocations of development expenditures compared with research. Cost only became an issue once it was clear that expert scientists and other personnel were available.

Sectors where research has grown

Our firm interviews described the driving factor for the location of research to be proximity of laboratories to universities, alliance partners, and technical experts. The actual location of these resources varies somewhat across industries, but in many industries, the U.S. has multiple centers of concentrated expertise. For pharmaceuticals, the Tri-state area and Boston areas are particularly plentiful locations of small biotech startup firms and cutting edge university science. In computers and telecommunications, Silicon Valley, the Tri-state area (again), and the Boston area (in this case referred to as the "Route 128 area") are locations of many potential alliance partners and expertise. And for motor vehicles, the Detroit area has plentiful facilities, partners, and specialists; for creative design work, southern California is also an important area in this regard.

It is not the case that other countries lack such technical centers entirely, but there are fewer of them and their resources are not as concentrated or strong, particularly in computers where the U.S. has led for many years. Institutional weaknesses in universities outside the U.S. were often cited for seeking relationships in the U.S. For instance, universities in Japan were criticized by both domestic and foreign firms as not giving incentives to researchers to focus on fields of commercial relevance, or to cooperate with industry. While individual researchers were a particular attracting point of several universities in Europe, they are more spread out, leading to fewer areas where the advantages of agglomeration can arise.

The importance of this explanation is supported by the fact that the U.S. has benefited from the growth in foreign research expenditures. But the observed growth is far greater than the growth in foreign-owned R&D. Thus, it is unlikely that the rise in research came solely from foreign investors (see Tables 5 and 10). Part of the rise in U.S. research since 1995 came from an increase in federal support for it, which reversed a declining trend during the early 1990s. But, this is not the major factor because since 1995 there has been a dramatic increase in basic research self-funded by industry

U.S. labs stay close to home?

The biggest increases in research in the U.S. occurred in nearly the same four industries in which we conducted interviews: pharmaceuticals, computers, telecommunications equipment, and motor vehicles. In each industry, basic research expenditure increased by at least $200 million from 1995 to 1999, more than doubling research shares in R&D. The largest increase was in pharmaceuticals, where the basic research share in R&D rose from 10% to 18% over these four years.[23]

Factors in Increased Development Shares

In contrast, development generally was located close to marketing and/or production facilities, and costs – including regulatory compliance – were key factors. Since growth in the U.S. was much faster than in the other major industrial countries during the late 1990s, markets were expanding quickly there. In addition, as we demonstrated earlier, U.S. costs have been declining relative to other countries. Moreover, regulatory compliance in the U.S. is a major issue in many of the industries where R&D expenditures are substantial. For example, in pharmaceuticals and motor vehicles, extensive safety and efficacy testing is required.

To be extended, including a concluding section.

[23] Because they bridge the SIC/NAICS changeover, these figures must be treated with some caution.

6. References

Adams, James D. (2001), “Comparative Localization of Academic and Industrial Spillovers,” NBER Working Paper No. 8292, May.

Ark, Bart van (1993), *International Comparisons of Output and Productivity*, Monograph Series No. 1, Netherlands: Groningen Growth and Development Centre.

____, and Timmer, M.P. (2001), “PPPs and International Productivity Comparisons: Bottlenecks and New Directions”, paper for the World Bank-OECD Seminar on Purchasing Power Parities.

Beise, Marian and Heike Belitz (1998), “Trends in the Internationalization of R&D – the German Perspective,” DIW Discussion Paper No. 167, April.

Branscomb, Lewis M. and Philip E. Auerswald (2002), “Between Invention and Innovation: An Analysis of Early Stage Technical Development,” National Institute of Standards and Technology, U.S. Department of Commerce, November.

Branstetter, Lee and Yoshiaki Nakamura (2003), “Is Japan’s Innovative Capacity In Decline?” NBER Working Paper No. 9438, January.

Brunner, E.D. (1967), *The Cost of Basic Scientific Research in Europe: Department of Defense Experience, 1955-1966,* RAND, Report for United States Air Force Project.

Cohen, W.M., Nelson, R.R., Walsh, J.P. (2002), “Links and impacts: the influence of public research on industrial R&D,” *Management Science* 48 (1), 1-23.

The Conference Board (1976), *Overseas Research and Development by United States Multinationals, 1965-1975: Estimates of Expenditures and A Statistical Profile*, New York, NY: The Conference Board.

Danzon, P.M. and Chao, L.W. (2000), “Cross-national price differences for pharmaceuticals: how large, and why?” *Journal of Health Economics*, 19, 159-195.

Dougherty, Sean M., Robert Inklaar, Robert H. McGuckin, and Bart van Ark (2002), “Performing Research and Development Abroad: International Comparisons of Value and Price,” Interim Report to the National Science Foundation, SRS.

Gassmann, O., von Zedtwitz, M. (2002), “Market versus technology drive in R&D internationalization: four different patterns of managing research and development,” *Research Policy* 31, 569-588.

Griliches, Zvi (1984), *R&D, Patents, and Productivity*, National Bureau of Economic Research, Cambridge, MA: University of Chicago Press.

____ (1986), Productivity, R and D, and Basic Research at the Firm Level in the 1970s, *American Economic Review*, 76(1), 141-154.

____ (1998), *R&D and Productivity: The Econometric Evidence*, National Bureau of Economic Research, Chicago and London: The University of Chicago Press.

Hall, B. and Long, W. (1999), "Differences in Reported R&D Data on the NSF/Census RD-1 Form and the SEC 10-K Form: A Micro-Data Investigation, " paper for the NBER, U.C. Berkeley, Oxford University, and BPRA, October.

Heston, A. and Summers, R. (1996), "International price and quantity comparisons: potentials and pitfalls," *American Economic Review*, 86(2), May.

Inklaar, R., Timmer, M.P. and van Ark, B. (2002), "International Comparisons of Prices, Output and Productivity Levels by Industry," paper for the International Conference on Input-Output Techniques, Oct. 10-15, 2002.

Jankowski, J. E. (1993), "Do we need a price index for industrial R&D?" *Research Policy* 22: 195-205.

Kiba, T., Sakuma, I. and Kikuchi, J. (1994), "Development of R&D Purchasing Power Parities (Summary)," National Institute of Science and Technology Policy Report No. 31, March.

Kravis, Irving, Heston, A. and Summers, R. (1982), World Product and Income: International Comparisons of Real Gross Product, Baltimore: The Johns Hopkins University Press.

Kuemmerle, W. (1999), "Foreign direct investment in industrial research in the pharmaceutical and electronics industries--results from a survey of multinational firms," *Research Policy* 28, 179-193.

Link, A.N. (1985), "The Changing Composition of Research and Development," *Managerial and Decision Economics* 6(2), 125-128.

____ (1996), *The Classification of Industrial R&D: Additional Findings*, Final Report to the National Science Foundation.

Link, A.N. and J.E. Long (1981), "The Simple Economics of Basic Scientific Research: A Test of Nelson's Diversification Hypothesis," *Journal of Industrial Economics* 30(1), 105-9.

Mansfield, E. (1988), "Industrial R&D in Japan and the United States: A Comparative Study," *American Economic Review Papers and Proceedings*, 72(2), 223-228.

____ (1995), "Academic research underlying industrial innovations: sources, characteristics and financing," *The Review of Economics and Statistics* 77(1), 55-65.

Mansfield, E., Teece, D. and Romeo, A. (1979), "Overseas Research and Development by U.S.-Based Firms," *Economica* 46, 186-196.

Mairesse, Jacques and Pierre Mohnen (2002), "Accounting for Innovation and Measuring Innovativeness: An Illustrative Framework and an Application," *American Economic Review: Papers and Proceedings* 92(2): 226-230.

Mowery, D.C., Nelson, R.R., Sampat, N.S., Ziedonis, A.A., (2001), "The growth of patenting and licensing by U.S. universities: an assessment of the effects of the Bayh-Dole act of 1980," *Research Policy* 20, 99-119.

National Science Board (2002), *Science and Engineering Indicators*, Arlington, VA: National Science Foundation (NSB-02-1).

National Academy of the Sciences (1999), *Harnessing Science and Technology for America's Economic Future: National and Regional Priorities*, Office of Special Projects, National Research Council.

Nelson, Richard R. (1959), "The Simple Economics of Basic Scientific Research," *Journal of Political Economy*, 67(3), 297-306.

Organization for Economic Cooperation and Development (1993), *Frascati Manual—The Measurement of Scientific and Technological Activities: Standard Practice for Surveys of Research and Experimental Development*, Fifth Edition, Paris: OECD Secretariat.

____ (2001), *Basic Science and Technology Indicators*, Paris: OECD Secretariat.

____ (2002), *Frascati Manual*, Preliminary Sixth Edition, Paris: OECD Secretariat.

Patel, P. and Vega, M., (1999), "Patterns of internationalization of corporate technology: location vs. home country advantages," *Research Policy* 28, 145-155.

Standard & Poor's (2002), *Compustat Global*, financial reports database.

Stokes, David E. (1997), *Pasteur's Quadrant: Basic Science and Technological Innovation*, Washington, D.C.: Brookings Institution.

Versbagen, Bart and Wilfred Schoenmakers (2002), "The Spatial Dimension of Patenting by Multinational Firms in Europe," Eindhoven University, Manuscript, June.

Zucker, L.G. and M.R. Darby (1995), "Virtuous Circles of Productivity: Star Bioscientists and the Institutional Transformation of Industry," NBER Working Paper No. 5342, November.

TABLE 1
Cost structure of Research and Development (share of expenditure) based on data collected in firm interviews

Interviewed firms	Labor	Other current	Capital
Research (10)	62%	37%	6%
Development (5)	44%	52%	5%

Differences vis-à-vis Overall R&D in industry based on national surveys

Firm minus national survey*	Labor	Other current	Capital
Research (10)	+22%	-20%	+4%
Development (5)	-0%	+2%	+1%

Sources: firm interviews, industry-level data from national R&D surveys (*)
Note: accounting rules for R&D restrict the assets that can be capitalized

TABLE 2
Public R&D information on interviewed companies

Company	Country	Industry	R&D Intensity				Coverage of Industry
			Company	Industry		Industry*	
				Weighted avg.	*Median*		
Akzo-Nobel	NLD	PHARMA	6.0%	6.1%	12.0%	8.8%	97.7%
Aventis	FRA	PHARMA	15.2%	12.7%	15.2%	7.7%	73.6%
Eli Lilly	UK	PHARMA					
Fujisawa	JPN	PHARMA	16.7%	10.1%	9.3%	10.4%	8.7%
Johnson & Johnson	USA	PHARMA	11.2%	14.2%	29.2%	13.7%	12.0%
Fujitsu	JPN	COMPU	7.4%	5.9%	3.4%	14.0%	22.8%
NEC	JPN	COMPU	6.4%	5.9%	3.4%	14.0%	19.5%
Hewlett-Packard	USA	COMPU	5.9%	7.5%	14.5%	8.2%	11.2%
Compaq	USA	COMPU	3.9%	7.5%	14.5%	8.2%	5.5%
Sun	USA	COMPU	11.5%	7.5%	14.5%	8.2%	8.7%
IBM	USA	COMPU	6.2%	7.5%	14.5%	8.2%	22.1%
Unisys	USA	COMPU	5.5%	7.5%	14.5%	8.2%	1.4%
Alcatel	FRA	TELCOM	11.3%	8.3%	10.0%	7.8%	51.4%
Infineon	DEU	TELCOM	21.0%	13.2%	15.2%	12.9%	97.9%
Solectron	USA	TELCOM	0.4%	11.9%	15.5%	4.8%	0.6%
Lucent	USA	TELCOM	16.5%	11.9%	15.5%	4.8%	27.9%
Sarnoff	USA	TELCOM	(a)	11.9%	15.5%	4.8%	(a)
Telcordia	USA	TELCOM	(a)	7.5%	14.5%	8.2%	(a)
Mazda	JPN	CAR	4.5%	3.8%	3.2%	3.4%	5.7%
Nissan	JPN	CAR	4.2%	3.8%	3.2%	3.4%	15.8%
Renault	FRA	CAR	5.3%	4.2%	4.3%	2.5%	52.8%
Ford	USA	CAR	4.6%	3.9%	2.0%	4.6%	53.2%
General Motors	USA	CAR	3.5%	3.9%	2.0%	4.6%	44.6%

Sources: *Compustat Global d*atabase; *National R&D Surveys; (a) Not publicly traded

Notes: R&D Intensity is defined as R&D expenditure as a percentage of total sales (Compustat) or gross output (national surveys). Coverage is defined as the company's R&D as a percentage of total R&D in the country for the industry.

TABLE 3
Comparison of R&D cost based on *PPP* Calculations and *Firm* Estimates

	Industry one		*Industry two*		*Industry three*		*Industry four*	
Country	PPP*	Firm**	PPP	Firm	PPP	Firm	PPP	Firm
France	- -		0	++	++		-	
Germany	++	+++	++	++	+++	+++	0	
Japan	+++	+++	+++	+++	+++	+	++	++
China		- - -		- - -		- - -		- - -
U.K.	-	-	0	0	+	-	- -	- -
U.S.	0	0	0	0	0	0	0	0

Symbols: "0" less than 5% difference with the U.S.;
"+" or "-" less than 15% positive or negative R&D cost difference with the U.S.;
"++" or "--" less than 25% cost difference; "+++" or "---" greater than 25% difference.

*Note: *"PPP" is based on industry-specific R&D PPP measure; **"Firm" is based on a direct estimate of R&D cost differences from a firm interview for a typical R&D project; Industry name is not shown to maintain firm confidentiality.*

TABLE 4a

Cost of R&D internationally relative to the U.S.

Price level (PPP/exch. rate)	1987	1995	1997	1998
France	107%	120%	101%	99%
Germany	109%	149%	126%	123%
Japan	100%	171%	137%	124%
Netherlands	108%	123%	98%	97%
United Kingdom	77%	86%	92%	94%
United States	100%	100%	100%	100%

TABLE 4b

Country-wide R&D PPPs, relative to the U.S.

PPPs for Mfg. R&D	(LCU per US$)			
France	6.45	5.99	5.87	5.85
Germany	1.96	2.13	2.18	2.16
Japan	144	161	166	163
Netherlands	2.19	1.97	1.92	1.92
United Kingdom	0.47	0.54	0.56	0.57
United States	1.00	1.00	1.00	1.00
Average annual exchange rate	(LCU per US$)			
France	6.01	4.99	5.84	5.90
Germany	1.80	1.43	1.73	1.76
Japan	145	94	121	131
Netherlands	2.03	1.61	1.95	1.98
United Kingdom	0.61	0.63	0.61	0.60
United States	1.00	1.00	1.00	1.00

Source: Dougherty et al. (2002)

Note: LCU is local currency units

TABLE 5

Proportion of industry R&D expenditures financed from foreign sources, by country (percentage of domestic expenditure)

Year	United States	Japan	European Union	Germany[a]	France	United Kingdom
1987	5.0	0.1	4.7	1.5	8.7	12.0
1988	5.8	0.1	5.9	2.1	9.2	12.0
1989	6.7	0.1	6.9	2.7	10.9	13.4
1990	7.9	0.1	7.6	2.7	11.1	15.5
1991	8.0	0.1	7.6	2.6	11.4	16.0
1992	9.2	0.1	7.4	2.5	12.0	15.0
1993	9.8	0.1	7.5	1.9	11.3	15.4
1994	10.8	0.1	8.0	2.0	11.2	16.0
1995	11.4	0.1	8.5	2.2	11.1	18.9
1996	11.0	0.1	9.1	2.2	11.4	21.5
1997	11.1	0.4	8.9	2.8	10.6	18.8
1998	13.2	0.4	8.9	2.7	9.3	22.0

SOURCES: NSF S&E Indicators Appx. 4-3, 4-45, 4-50, OECD S&T Database

NOTE: (a) Refers to West Germany from 1987-90

TABLE 6

Foreign and Domestic R&D Expenditure in the United States

(Constant 1995 Dollars using GDP Deflator)

Expenditures	1987	1995	2000
Domestic-owned	107,793	114,984	157,084
Foreign-owned	5,659	14,846	23,939
Total R&D	113,452	129,830	181,023
	Percent of Total R&D		
Domestic-owned	95%	89%	87%
Foreign-owned	5%	11%	13%
Total R&D	100%	100%	100%

Annual Growth Rate	1987-95	1995-00
Domestic-owned	0.8%	6.4%
Foreign-owned	13%	10%
Total R&D	1.7%	6.9%

Note: only R&D performed by business enterprises included

Sources: NSF S&E Indicators (tbls 4-3, 4-50), BEA Survey of Foreign Affiliates 2002

TABLE 7a

R&D performed by foreign companies in the United States, by country of owner
(Millions of current U.S. dollars)

Country of Ownership	1987		1995		1998	
Japan	133	3%	1,259	8%	2,578	12%
France	332	7%	1,529	10%	1,905	9%
Germany	824	18%	3,563	24%	4,880	22%
Netherlands	540	12%	786	5%	985	4%
United Kingdom	790	18%	2,316	16%	3,685	17%
Other countries	1,878	42%	5,393	36%	8,040	36%
Total Foreign R&D in U.S.	4,497	100%	14,846	100%	22,073	100%

SOURCE: NSF S&E Indicators 4-50

NOTE: Data are for nonbank U.S. affiliates with more than 50 percent foreign ownership

TABLE 7b

R&D performed abroad by foreign affiliates of U.S. companies, by country
(Millions of current U.S. dollars)

Country of Location	1989		1995		1998	
Japan	1,000	13%	1,286	10%	1,030	7%
France	521	7%	1,271	10%	1,321	9%
Germany	1,726	22%	3,068	24%	3,042	20%
Netherlands	367	5%	495	4%	501	3%
United Kingdom	1,718	22%	1,935	15%	3,144	21%
Other countries	2,590	33%	4,527	36%	5,948	40%
Total R&D Abroad	7,922	100%	12,582	100%	14,986	100%
As share of U.S. domestic R&D	73,501	11%	108,652	12%	145,016	10%

SOURCE: U.S. Bureau of Economic Analysis, U.S. Direct Investment Abroad 2002

NOTE: Data are for majority-owned companies (more than 50 percent ownership)

TABLE 8
Global Shares of R&D Expenditure
(Expenditure converted to USD using R&D PPPs and GDP Deflators*)

R&D Expenditure	1987	1995	1997	1998
Total Expenditure (1995 USD)	148,190	223,258	256,737	271,404
France	7%	8%	8%	7%
Germany	13%	10%	9%	9%
Japan	30%	26%	25%	24%
United Kingdom	8%	7%	6%	6%
United States	41%	49%	52%	53%
Total	100%	100%	100%	100%

Time Period	1987-95	1995-97	1997-98
Compound annual growth rate	5%	7%	6%

SOURCES: authors' analysis, OECD S&T Database

TABLE 9a

Global Shares of Research Expenditure (preliminary estimates*)

(Expenditure converted to USD using R&D PPPs and GDP Deflators)

Research	1987	1995	1997	1998
Total Expenditure (1995 USD)	8,563	11,828	15,642	18,305
France	5%	6%	5%	5%
Germany	11%	10%	8%	7%
Japan	35%	33%	26%	20%
United Kingdom	8%	5%	5%	4%
United States	42%	45%	56%	64%
Total	100%	100%	100%	100%

Time period	1987-95	1995-97	1997-98
Compound annual growth rate	4%	15%	17%

TABLE 9b

Global Shares of Development Expenditure

(Expenditure converted to USD using R&D PPPs and GDP Deflators)

Development Expenditure*	1987	1995	1997	1998
Total Expenditure (1995 USD)	139,627	211,430	241,095	253,099
France	8%	8%	8%	7%
Germany	13%	10%	9%	9%
Japan	30%	26%	25%	25%
United Kingdom	8%	7%	6%	6%
United States	41%	49%	52%	53%
Total	100%	100%	100%	100%

Time period	1987-95	1995-97	1997-98
Compound annual growth rate	5%	7%	5%

Note: *Development expenditure based on difference between total R&D and basic research. This is the same as applied research plus experimental development, except Germany, where only basic research is separately collected.

SOURCES: authors' analysis, OECD S&T Database

TABLE 10

Analysis of U.S. R&D Expenditure Composition Changes - Performed by Industry

(Constant 1995 Dollars using GDP Deflator)

Annual Growth Rate	1987-1995	1995-2000
Research	0.7%	20%
Development*	1.7%	6.1%
Total R&D	1.7%	6.9%

Expenditures	1987	1995	2000
Research	5,261	5,569	14,111
Development*	108,191	124,261	166,912
Total R&D	113,452	129,830	181,023
	Percent of Total R&D		
Research	5%	4%	8%
Development*	95%	96%	92%
Total R&D	100%	100%	100%

Note: *Development is defined here as Applied Research plus Experimental Development

Sources: NSF S&E Indicators, authors' analysis

TABLE 11

Country Shares of Research as a Share of Total R&D - Funded by Industry (based on business enterprise R&D in current expenditure)

Share of total R&D	1987	1995	1997	1998	2000
France	3.7%	4.2%	4.4%	4.4%	
Germany	5.0%	5.1%	5.2%	5.2%	
Japan	6.6%	6.6%	6.2%	5.6%	
Netherlands	18%				
United Kingdom	4.7%	4.3%	4.8%	4.8%	
United States	5.8%	5.0%	6.6%	8.1%	7.8%

Note: Only business enterprise basic research included; U.K. figure for 1987 is from 1989; German figure for 1998 is estimate.

Source: OECD S&T Indicators, authors' analysis