PERFORMING RESEARCH AND DEVELOPMENT ABROAD

International Comparisons of Costs and Value[1]

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1. Introduction

In the last decade, Research and Development (R&D) spending increased substantially both here and abroad. At the same time there appears to have been significant changes in the way R&D spending is distributed geographically, organizationally and by type of activity undertaken. For example, recent NSF reports indicate that R&D is becoming more internationalized as companies increase spending in foreign affiliates, create new international partnerships and alliances, and pursue cross-border of mergers and acquisitions to procure intellectual assets.

This globalization of R&D activities raises many measurement issues, particularly in the area of comparisons across countries and sectors. A major part of this project, and the primary focus of this one-year status report, is the development of comparable quantitative measures of “real” R&D effort for six major industrial countries – France, Germany, Japan, The Netherlands, United Kingdom and United States – and 13 manufacturing industries.

A second part of the project studies the composition of R&D activities within the firm and how they are structured. This work examines how well current NSF surveys are capturing R&D

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activities and, where necessary and possible, suggest modifications. The analysis relies heavily on interviews of major global R&D performers and is designed to help interpret measured differences in R&D effort across countries. A key motivation for this work is recent reports that the organization and character of R&D activities has shifted dramatically within and across countries. There is concern that national surveys of R&D are not adequately accounting for these shifts.

One aspect of these shifts involves changes in the distribution of Research and Development across international boundaries. Another, and perhaps more important, is the emphasis by many science and technology (S&T) policy analysts on the potential impacts of globalization and competition, coupled with declines in governmental funding, on shifts in R&D spending toward specific business interests and away from more basic scientific inquiry. Shifts away from "basic" research – research that produces "fundamental knowledge" – have been of particular concern to many analysts who see basic research as an upstream driver of invention and innovation.[2]

The organization of the interim report is as follows. Section 2 provides and overview of the research design and strategy. Section 3 summarizes the main empirical findings and some implications that appear warranted from the evidence to date. The details of the work are reported in a Supplement to the Interim report. Sections 4, 5, 6 and 7, along with several Appendices outline in detail how the data were constructed and provide more specifics on the findings reported in Section 3. Section 4 provides a review of the empirical literature on international comparisons of R&D. Section 5 focuses on the development of comparable measures of industry output and R&D inputs across countries. Section 6 turns to comparison of R&D intensities, a principal S&T indicator used to measure effort or sacrifice. Section 7 discusses the results of our interviews of R&D executives of large multinational firms in four industries with substantial R&D activity.

[2] While a shift from basic to applied research may mean that R&D expenditures have less economic impact, the competition that is driving the shift could be improving research productivity. This work in the coming year, however we note that improved productivity is consistent with our interviews that suggest that firms are making greater use of university researchers and outsourcing in the research process.

2. Research Design and Procedures

Aggregate ratios of R&D to national income and trends of R&D spending for industries and even firms are the basis for comparisons of R&D activities across countries. While there are many problems of interpretation of international expenditure patterns, adjustments for differences in local currencies using purchasing power parities (PPPs) are necessary for valid comparisons of R&D expenditures and output. Developing the PPPs required and assessing the quantitative impact of failure to adjust is a major goal of this project.

A purchasing power parity (PPP) is defined as the number of currency units required to buy goods equivalent to what can be bought with one unit of the currency of a base country (the U.S. in our study). Thus, a PPP is simply the ratio of the values of comparable goods in two countries' local currency prices. It has the same units as an exchange rate. For example, with the U.S. as the base country, the PPP for France is denominated in Francs per dollar. Using PPPs to adjust outputs or inputs in national currency values produces comparable values in the spatial dimension. In this sense, PPPs are comparable to commonly used deflators that transform the nominal values of time series like GDP into *real* values that account for inflation.

Market exchange rates also provide a measure a currency's relative international buying power. They appear to be a natural substitute for PPPs but are not suitable for most spatial adjustments of prices in national currencies. There are many reasons why exchange rates are not good substitutes for PPPs. Of particular relevance to comparisons of R&D expenditures, there is no straightforward link between exchange rate values and the relative prices of goods not traded internationally. Aside from theoretical considerations, use of exchange rates can be highly misleading because the magnitude of the difference between exchange rates and PPP adjustments is often very large.[3]

In practice, international comparisons use economy-wide expenditure PPPs. This procedure implicitly assumes two questionable things: first that the ratio of input to output prices is the

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[3] Exchange rates are vulnerable to a number of distortions that have little or nothing to do with the differences in relative prices across economies. These points are emphasized in *Science and Engineering Indicators*, "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data" (NSF, 1999, 2000, 2001).

same across countries and second that the composition of research and development activities is the same across countries. While use of industry-level data on R&D and output partially addresses the composition issue, the issue of adequate measures of prices and costs remains a fundamental problem.

The results of our interviews of R&D executives of large multinational firms in high and medium technology industries -- pharmaceuticals, office and computing machinery, telecommunications equipment, and motor vehicles – help to benchmark the statistical work based on PPP analysis and provide specific information about the nature and organization of R&D in intensive R&D industries. So far, about two thirds of the planned interviews of large R&D performers are completed. These interviews were primarily in the U.S. and Japan. In the remainder of the project more interviews will be conducted in Europe and the U.S. (with some comparisons to China and India as well). While we have not completed the interviews nor analyzed all the data collected so far in detail, some patterns with regard to the structure of the R&D process and its organization in the firm are becoming clear.

3. Preliminary Findings

Table 3-1 provides an overview of the basic comparison measures developed. It shows for example that Germany and Japan have R&D costs well above those of the U.S. for overall manufacturing, while the U.K.'s costs are lower. France and the Netherlands R&D costs are about the same as the U.S. These differences reflect two factors, differences in the cost of R&D inputs and differences in the proportions of R&D inputs used in R&D. As it turns out, differences in input costs rather than differences in proportions (weights) make the biggest impact on cross-country comparisons.

R&D intensity also differs widely across countries reflecting the variations in both the costs of R&D inputs and adjustments for price differences in output. Column 4 shows that Japan, the United States and France devote more than 2.5% of their country's output to R&D, while the three other countries in our study only devote about 2%.

Table 3-1, Relative cost of Manufacturing R&D relative to the U.S. (1997)

	R&D Cost	**R&D PPP**	**Output PPP**	**Real R&D Intensity**
France	100.7%	5.88	5.59	2.5%
Germany	126.0%	2.18	1.84	2.0%
Japan	136.9%	165.6	152.0	2.8%
Netherlands	98.2%	1.91	2.10	1.9%
U.K.	88.7%	0.53	0.67	2.1%
U.S.	100.0%	1.00	1.00	2.6%

Note: Based on Tables 5-5, 5-6, and 6-2. PPPs are bilateral, denominated in national currency units per U.S. dollar.[4] R&D Intensity is R&D expenditure as a share of gross output, with PPP adjustments.

These intensity measures differ from the measures currently available for international comparisons of R&D. For example, these adjustments are lower German manufacturing R&D

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[4] In this interim report, we calculated PPPs bilaterally with the United States. Preliminary tests with multilateral methods suggest these rankings are transitive.

intensity from 91% of the U.S. to 77% after adjustment, and raise U.K. manufacturing R&D intensity from 67% to 82% of the U.S. Moreover, the impacts of these adjustments are magnified when examining individual industries. Interviews of R&D firms have so far matched quite closely with the overall character of these relative costs (see Section 7).

A key finding of our interviews is that there are striking differences in the content and motivations of activities encompassed in R&D. This reflects both the output of the process (more uncertain) and the resources (more Ph.D.s for example) used to produce it. Moreover, while we have not yet fully analyzed the firm specific data, the patterns appear to vary greatly by industry. It seems clear that firms are quite capable of reporting R and D activities separately and this distinction is important strategically. It is not so clear that firms can report R&D expenditures in basic, applied and development categories.

Internationalization of Research is much more limited than for Development and is most often undertaken to work with particular universities or to utilize assets acquired in a merger. The Development activities, in contrast, have a deliberate international focus. Decisions on where they will be done turn on such things as destination market, manufacturing plant location, and regulatory issues and to a lesser extent costs. While we are still exploring these distinctions and completing a full literature review of work done in this area, these issues have dominated nearly every interview we have conducted.

SPECIFIC RESULTS

- *R&D-specific PPPs differ substantially from both the economy-wide (GDP) PPPs and market exchange rates*

Conversions of aggregate R&D expenditures between countries using GDP PPPs – as used in current practice – differ by as much as 19% relative to R&D PPPs, as shown in Table 3-2. Use of market exchange rates leads to differences as large as 29%.[5] The R&D PPPs represent the cost in local currency of one U.S. dollar's worth of R&D, and they do not appear to have any systematic relationship with the GDP PPPs or the exchange rate. That said, for some countries the differences turn out to be rather small, regardless of the conversion factor used. For instance, in

[5] The differences we calculate are not as large as those found in previous studies of the 1970s and 1980s described in Section 4, and while still large, are not enough to change the ranking of real expenditure on

the Netherlands the three conversion factors yield approximately the same results at the level of overall manufacturing. This appears to be simple coincidence rather than a derivative of a broad economic principle (such as the law of one price), since even in the Netherlands, individual industries vary widely. Since the largest component of R&D expenditure is labor, a difference in their wage rate has a large effect on the R&D PPPs. Other current and capital expenditure items generally have less influence.

Table 3-2: Comparison of Manufacturing R&D Purchasing Power Parities (PPPs) with GDP PPPs and Market Exchange Rates (MER)

	R&D PPP	GDP PPP	difference	MER	difference
France	5.88	6.51	11%	5.84	-0.7%
Germany	2.18	1.94	-11%	1.73	-21%
Japan	165.6	163	-1.6%	121	-27%
Netherlands	1.91	1.97	3.1%	1.95	2.1%
U.K.	0.53	0.63	19%	0.61	15%

Source: Tables 5-4 and 5-5.

- *R&D PPPs vary widely across industries*

While the R&D PPPs have a strong country component, there is substantial variation across industries and within countries. R&D PPPs for particular industries depart significantly from the manufacturing-wide R&D PPP, and even more from the GDP PPP and MER. The spread in the R&D PPP from the most expensive to least expensive industry in a country varies between 39% for France, to 85% for the Netherlands, as shown in Table 3-3. There are some strong similarities among the cost ranking of industries. For instance, transportation is the most expensive manufacturing industry for performing R&D in Germany, France, and Japan. In addition, in the Netherlands, France, U.K., and Japan, fabricated metals is the least expensive industry for performing R&D.

These differences imply that comparisons of R&D performed in particular industries requires industry-specific conversion factors; using R&D-wide or economy-wide PPP converters is often misleading. These results reinforce similar findings in previous R&D PPP studies and

R&D in manufacturing in 1997 among the countries in this study.

the analogous findings of Jankowski (1993) and Mansfield (1987) for inter-temporal price deflators.

Table 3-3: Differences in R&D PPPs across 13 Industries (1997)

	Highest PPP	Lowest PPP	Ratio	Coeff. of Variation
France	6.94 (transport)	4.98 (fab. metal)	1.39	0.09
Germany	2.91 (transport)	1.65 (food)	1.77	0.16
Netherlands	2.66 (petroleum)	1.44 (fab. metal)	1.85	0.15
Japan	206 (transport)	134 (fab. metal)	1.54	0.14
U.K.	0.73 (petroleum)	0.41 (fab. metal)	1.78	0.17
Average			1.67	0.14

Source: Table 5-5.

- *R&D intensity comparisons are substantively affected by price and cost adjustments*

In developing measures of R&D intensity – the ratio of R&D expenditures to output – we used industry-specific PPPs for both R&D and for industry output (at producer prices). We find (Table 3-4) that the standard practice of using unadjusted R&D/output measures exaggerates R&D intensity for some countries relative to the United States and reduces it for others. For instance, German R&D intensity for manufacturing is about 91% of the U.S. level in current prices and only 77% using the adjusted figures. On the other hand, U.K. intensity increases from 67% of the U.S. to 82% with the adjusted figures. In fact, the gap with the U.S. widens for France and Germany, but narrows for The Netherlands, Japan, and the U.K. Comparisons using value added instead of gross output.

Adjustments for the cost of R&D input components have a bigger impact than adjustments for differences in the price of industry output. One factor that may help to explain this is that largest input into R&D is labor, which is generally not an internationally traded good. In contrast, many industry outputs are readily traded commodities.

Table 3-4: Nominal and Real R&D intensity in manufacturing for 1997

(as a % of gross output)	Nominal (using national currency)		Real (with PPP adjustments)	
	R&D Intensity	Relative to U.S.	R&D Intensity	Relative to U.S.
Germany	2.4%	91%	2.0%	77%
Netherlands	1.8%	67%	1.9%	73%
France	2.6%	100%	2.5%	94%
U.K.	1.8%	67%	2.2%	82%
Japan	3.0%	116%	2.7%	102%
U.S.	2.6%	100%	2.6%	100%

Sources: Tables 5-1 and 5-2

- *Caution is important when interpreting information from worldwide R&D surveys because of inconsistencies between the U.S. and other countries' R&D surveys*

Despite the *Frascati Manual's* recommendations for harmonization of worldwide R&D surveys, there are some critical differences in countries' surveys. Here we highlight some with implications for developing PPP-adjusted R&D measures.

In the U.S. R&D Survey personnel counts of research scientists and engineers are collected but no information is available for support personnel. Moreover, the labor expenditure question covers all employees, requiring estimates of support personnel in order to calculate average wage levels. Nonetheless, the support share in R&D labor expenditure has become smaller over time and more uniform across countries.

Most countries' R&D Surveys collect capital expenditures, yet the U.S. has collected "R&D depreciation" expenditure since 1998. While this phrasing is conceptually superior, the responses depart from expenditure shares observed in other countries (1% in U.S. vs. 6% minimum elsewhere). This makes it difficult to interpret the responses. Interviews suggested that some companies confuse the question with (capitalized) software development depreciation.

Only three countries ask about the material share in R&D expenditure, making it impossible to utilize this information in many comparisons. Japan and the Netherlands set particularly good examples for collecting information – using multiple approaches, so the accuracy of responses can be more readily assessed (i.e. both capital expenditure and depreciation).

The interviews raised some important warnings. The cost structure of R&D expenditure varies greatly across firms and different types of activities. For example, according to the expenditure data we have collected during firm interviews, Research expenditure is generally more labor-intensive than Development – which tends to be more materials and capital-intensive. This suggests that R&D surveys should break out cost information by type of R&D.

More fundamentally, the consistency of reporting on the scope of R&D is also a major concern. In many cases, accounting or finance units in firm headquarters apparently completed the RD-1. 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. Moreover, R&D that is done within business units (as opposed to central laboratories) may not be identified it is collected to obtain tax or subsidy benefits. A surprisingly wide range of interpretations of the coverage (definition) of R&D were observed, even for firms in the same industries. There was very low awareness of national R&D surveys' existence among senior R&D executives. Nearly unanimously, the completion of the RD-1 form is done without their input , and most surprisingly, in only a few cases were they able to locate a copy of a recently completed form in their organization.

- *Research differs in important ways from that of Development both in content and internationalization*

We have observed a striking difference in the content and motivations of R vs. D activities in the interviews. Research activities are described as much more fundamental ("blue sky") in their focus and uncertain in their output than Development work. They are typically exploring new technologies – without particular products in mind. Moreover, they have a much longer time horizon and involve projects that are not predictable. While there was some disagreement about what constituted *applied* Research, the boundaries between "big R" Research and "big D" Development were considered to be straightforward by most companies. Much of the Research activity (and all of the basic Research) is housed in central research laboratories, to the extent it is done at all.

Development is a predictable activity in the sense that the output and resources required are generally known at the outset. Thus Development involves far less technical risk and uncertainty. And while this work goes by different names in different industries, it is focused on a particular product or process concept.[6]

These differences in Research and Development have important implications for internationalization. The incentives to locate Research outside a company's home country appear to be strikingly more limited than for Development. Some research is done overseas to enable work with particular scientists at overseas universities. More often, when research is performed outside the home country, it arises as a consequence of a merger or acquisition. Internationalization is even described as a barrier to collaboration, and most research projects were described as being done primarily in one location (in contrast to the motto "24/7" recently popularized).

Development activities are often deliberately internationalized and tied to a destination market and manufacturing plant location. Institutional issues, such as regional communications standards and regulatory approval requirements are also very important. In the companies we spoke with, Development is typically done in far more countries than Research. This work is highly focused on particular business objectives, typically dwarfing laboratory research expenditure by 10:1 or more. Such differences between R and D ran throughout the interviews conducted to date. However, many of the interviews have been with firms located in the U.S. and Japan; we will be interviewing more European firms in the next phase of the project, thereby refining these distinctions. Moreover, a literature review suggests that the differences we have identified regarding the content and internationalization of R and D were present in previous examinations of these issues.

[6] In contrast to the clarity with which companies describe the distinctions between R and D, interpretations about the overall scope of R&D varied considerably. Similar companies have multiple interpretations about what constitutes development, with some including engineering and even marketing activities – often based on organization of business units. These observations are consistent with Link's (1996) findings, and we discuss this issue in more detail in Section 7.

Implications of Findings for National R&D Surveys

The preliminary findings have a number of important implications regarding the measurement of international R&D activities:

- Firms should report expenditures and related information for Research and Development separately. Creating a separate research survey or making it a separate part in the current survey may not be much of an extra burden for respondents and could provide valuable information on Research activities. The R&D surveys and supplemental surveys such as the foreign affiliate survey should also include questions that separate R from D. Most firms we talked to had no trouble reporting on their Research activities, but much more trouble in separating Development from the business units of which they were a part.
- The distinctions between basic and applied research are not very useful. The conceptual distinction between applied and basic in the NSF questions revolves around whether or not the research is aimed at a specific need. Applied is targeted at a specific application and basic seeks new knowledge or understanding. These descriptions suggest that the output of the process is uncertain. Since business seems to focus on the distinction between certain and uncertain outcomes, applied research would appear at first to be a part of Research. However, it is more likely that applied research is part of Development or a very minor and hard to identify part of Research. We will focus more closely on this issue in the remaining interviews, but the information we have so far suggests that it adds confusion.

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Supplemental Details to Support Interim Report Observations and Outline Empirical Methods (PRELIMINARY DO NOT CITE WITHOUT PERMISSION OF AUTHORS)

4. Literature Review

4.1 Previous literature on R&D PPPs[7]

From the 1960s onwards, there has been sporadic interest in detailed international comparisons of R&D. This is in sharp contrast to the countless studies of R&D attempting to link it with productivity growth, the market value of the firm and the number of patents. A number of the studies that do make international comparisons also tend to be U.S.-centered since they compare R&D performed by (U.S.) companies in their home country to R&D performed by their foreign affiliates. The calculation of R&D-specific PPPs has been attempted a number of times and we summarize these studies in Table 4-1. This Table shows the relative total and labor cost levels compared to the U.S.

Freeman and Young (1962) performed the first of these studies. The R&D data used in this study were not yet collected on a comparable basis since the first edition of the Frascati Manual only came out in 1963. Freeman and Young (1962) estimate a PPP for R&D as a whole for a number of countries by breaking up total R&D expenditure into labor costs, materials, other current expenditure and capital expenditure. For labor costs they calculate the wage cost per worker in R&D. They assume this is also appropriate for other current expenditure, while they assume the exchange rate holds for materials and capital expenditure. As the authors acknowledge, these are very crude assumptions, which is reflected in the title of their report (an 'experimental international comparison').

Brunner (1967) compares a subset of R&D across a number of European countries. He compares the cost of research projects subcontracted by the U.S. Department of Defense. For these projects, subcontractors supply budget sheets, which contain data on total costs, including wages, benefits, support and overhead costs. The comparability issues are likely to be smaller than in the Freeman and Young (1962) study, since the Department of Defense imposes similar budget standards on all subcontractors. However, this only looks at a very specific subset of R&D and the budgets may not include all R&D costs, like capital expenditures.

The work by MacDonald (1973) extends the previous two studies to sixteen OECD countries by calculating R&D PPPs relative to the UK.[8] He distinguishes between labor cost, other current cost and capital expenditure. For the countries from the Brunner (1967) study, he uses wage data for scientists and for technicians based on that study. For the other countries he relies on average wage costs (total labor cost over total number of R&D workers). MacDonald (1973) estimates a capital PPP based on price relatives from trade statistics, which he weighs by aggregate quantities for these products. For other current expenditure, he assumes the exchange rate is applicable. Based on these figures, he finds as the two extreme observations that the U.S. is around 40% more expensive and Japan 70% cheaper than the UK.

In 1979, the OECD also published a study, which showed calculations for R&D deflators for the period 1966-1976 and R&D PPPs for 1970. They distinguish four cost categories: labor, other current costs, land and buildings and instruments and equipment. For these categories, average cost shares across countries are calculated and applied. The labor PPP was calculated as the average labor cost per R&D worker. A PPP for other current expenditure was proxied as government current expenditure other than salaries from ICP studies. The two capital categories are also ICP-based: land and buildings on non-residential/commercial buildings and for instruments and equipment one or more (electrical) machinery items.

The most recent study that estimates R&D PPPs is Kiba, Sakum and Kikuchi (1994). The countries they cover are France, Germany, Japan and South Korea versus the U.S. They rely heavily on ICP expenditure PPPs in their calculation, supplemented by the exchange rate for a few specific products. The breakdown into cost categories is more refined than in previous studies since they also distinguish materials spending from other current expenditure and they break down capital expenditure into machinery & equipment, land & building and other assets. Since that fine a breakdown is not available for all countries, they make a number of assumptions based on countries were these data are available. They then allocate ICP PPPs each of these cost categories. This selection is based on the entry for dedicated R&D establishments in the various input/output (I/O) tables. For some products, like petroleum and coal products, the exchange rate is used instead of a PPP since these are heavily traded goods. The products within each cost

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[7] Shannon Mok provided excellent research assistance on this section.
[8] In Table 4-1, we converted these to cost levels relative to the U.S. to facilitate comparability. This is appropriate since all PPPs are aggregated from individual cost category PPPs using UK weights, in effect

category are then combined to form an overall PPP for that category.[9] These are then weighted using R&D expenditure shares to form aggregate R&D PPPs for 1985. The other countries usually come out at higher cost levels due to higher labor cost levels. However, their use of ICP PPPs for labor costs is questionable, since these PPPs only refer to governmental and educational employees and may not be representative of the average R&D worker in the private sector as the OECD (1979) notes.

Apart from these studies, which are (more or less) based on aggregate results, there are two studies that do not take a top-down approach but more bottom-up. There is a study by The Conference Board (TCB, 1976) and one by Mansfield, Teece and Romeo (1979), both of which study R&D by U.S. firms both in the U.S. and in their foreign affiliates. TCB (1976) does not develop full R&D PPPs, but they do report on the relative salaries of scientists & engineers and support staff. For both categories, the salaries within the U.S. are higher than abroad. Mansfield *et al.* (1979) reports on a survey of 35 U.S. firms with foreign affiliates. Nineteen of these report on the cost level abroad compared to that in the U.S.. They find that in 1965, the U.S. was still substantially more expensive (20-40%), but that in 1975, this gap had mostly closed (only 4-10% more expensive). These results are not directly comparable to those of the other studies since they are based on surveys, which ask the respondent to give their estimates of relative costs.

Looking at Table 4-1, we see that over the past forty years, PPPs have been calculated for 19 countries (plus Europe as a whole) versus the U.S., with the MacDonald (1973) study giving the most comprehensive country coverage. Prior to our study of 1997, the U.S. was consistently the most expensive country to do R&D in. This was especially true in the 1960s when total costs in the other, mostly European, countries were about half of that in the U.S. Labor costs were even lower, at between 30-40% of the U.S. level. During the 1970s and 1980s, the cost levels seem to have steadily increased relative to the U.S. The study by Mansfield *et al.* (1979) gives the clearest result on that score, but this result is mirrored in the other studies. For example, Japan had a relative cost level of only 35% of the U.S. in 1963-4 (MacDonald, 1973). In 1970, this had risen to 57% (OECD, 1979) and in 1985 it stood at 81% (Kiba *et al.*, 1994). The final two columns show the relative R&D cost levels in manufacturing based on our study. Since 1985, most countries seem to have caught up or surpassed the U.S. cost level. A more careful study is

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creating a Laspeyres-type index. Although the Laspeyres index has other problems, it is at least transitive.

[9] The PPPs for other current expenditure are weighted based on ICP GDP expenditure weights.

needed to determine the causes, but the general catching up of productivity and income levels seems a likely candidate. Overall, relative labor costs seem to have stood at a lower level than total costs in most countries throughout the 1960-1985 period, with the exception of France and Germany, where labor became relatively more expensive in 1985. In general, however, one should be careful comparing these numbers, since as shown above, the methodology differs significantly between studies.

These differences, but also the similarities suggest both a number of extensions and some methodological conclusions. First of all, the most recent PPPs are for 1985, so more recent data would be helpful in assessing changes over the past 15-20 years. Furthermore, the PPPs that have so far been calculated cover R&D as a whole, but this hides likely differences between industries. Price deflators of specific industries also show large differences in their change over time and other variables, like wages, also show large cross-industry variation. It would therefore be unreasonable to assume that one R&D PPP fits all industries.

As to the methodology for calculating these PPPs, there seems to be a relative consensus for the calculation of the labor component. As OECD (1979) notes, an ideal approach would be to calculate the labor cost per employment category (scientist, technician or support), but data limitations prevent this method from being implemented. The second-best option is to calculate the average labor cost per R&D worker. The third route Kiba *et al.* (1994) choose, using ICP government and educational labor PPPs for as a proxy for a R&D labor PPP, is likely to be inferior to the second option.

Calculating a PPP for the other current expenditure category is less straightforward. It is not really clear what type costs this category includes and which PPPs to select for those categories. In general, there are two major categories, purchased goods and purchased services. The first would include materials costs (raw, non-durable goods) but depending on depreciation rules also machinery and instruments. The second major component, frequently referred to as overhead costs, can include anything for building rents to scientific journals.

The method from MacDonald (1973), who uses the exchange rate for materials and the labor PPP for overhead is probably too crude. Overhead for example, includes much more than simply extra labor cost. OECD (1979) and Kiba *et al.* (1994) take a more promising approach by using product-specific ICP expenditure PPPs to come up with a PPP for this cost category.

This method has pitfalls however. Kiba *et al.* (1994) use the I/O tables to identify the major cost categories within the R&D industry. If these tables are sufficiently comparable across countries, this could be a very useful procedure. However, our research indicates that this frequently is not the case. The problem is that the type of inputs these industries use depend on the institutional structure of the country and the related issue of what facilities are deemed in the R&D labs by the data collectors. German R&D firms for example get a significant share of their intermediate inputs from the education sector, while other in other countries, this share is non-existent (see Appendix 5.5.2). In the U.S. only stand alone labs are included in this category and their inputs are likely to be very different from integrated facilities.

The OECD (1979) approach to weighting the various product PPPs is also problematic since economy-wide expenditure weights are unlikely to reflect the cost structure of R&D labs. Also, the price consumers pay for final consumption goods or firms for investment goods may not match with intermediate input purchases by R&D firms.

Finally, the procedures used by MacDonald (1973), OECD (1979) and Kiba *et al.* (1994) to come up with capital PPPs are again reasonably straightforward. The problem with the use of import and export prices by MacDonald (1973) is that they may not reflect prices paid for similar goods by R&D labs. It is probably more appropriate to select one or more PPPs for both land and buildings and instrument and equipment, such as done by the OECD (1979) and Kiba *et al.* (1994) using ICP expenditure PPPs.

A final problem arises from the R&D expenditure data by cost category. It is far from clear whether companies in different countries report on R&D costs in a similar way. So for example in one country, companies may include purchases of new computers under current expenditure while in others it is classified as a capital expenditure.

Overall, it is not likely that all problems associated with calculating R&D PPPs can be resolved. However, as we describe in the rest of this report, in various areas we can make improvements on the methods described here, or at least avoid some of the more questionable methods and assumptions.

Table 4-1, Relative R&D cost levels in various studies (US=100)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Total	Labor	Total[a)]	Total[b)]	Labor[b)]	Total	Labor	Total[c)]	Total[c)]	Total[c)]	Total	Labor	Total	Labor
	1962	1962	1961-2	1963-4	1963-4	1970	1970	1965	1970	1975	1985	1985	1997	1997
Austria			17.2	40.0	16.7									
Belgium	58.8	41.7	42.9	54.5	27.3	71.2	66.6							
Canada				85.7	60.0			82.0	86.0	96.0				
France	66.7	50.0	42.4	60.0	33.3	73.3	67.3				76.8	80.6	100.6	99.7
Germany	58.8	43.5	28.7	60.0	33.3	70.6	59.3				85.4	91.2	125.8	114.4
Greece				54.5	27.3									
Ireland			39.2	54.5	30.0									
Israel			64.0											
Italy			23.8	50.0	25.0	71.7	67.8							
Japan				35.3	12.5	57.1	34.5	56.0	60.0	90.0	81.3	75.5	136.9	103.6
South Korea											33.9	21.3		
Netherlands	52.6	35.7		66.7	37.5	68.1	63.0						98.3	88.4
Norway				66.7	37.5									
Portugal				46.2	20.0									
Spain				40.0	17.6									
Sweden			33.0	66.7	42.9	86.4	92.0							
Switzerland			46.4			90.4	100.0							
UK	55.6	40.0	34.0	60.0	30.0	58.8	41.7				68.0	59.3	91.7	72.7
USSR	33.3	26.3												
Europe								68.0	74.0	93.0				
US	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Notes:
[a)] Refers to research costs only. Calculated as geometric average of US and other country weighted PPP over the market exchange rate.
[b)] Originally cost level relative to UK. Calculation assuming transitivity
[c)] Refers to foreign affiliates of US firms only

Sources:

Columns (1) and (2)	Freeman and Young (1962), table A, p. 94
Column (3)	Brunner (1967), Table 11, p. 43
Columns (4) and (5)	MacDonald (1973), Table I, p. 481
Columns (6) and (7)	OECD (1979), table IV, p. 170
Columns (8), (9) and (10)	Mansfield *et al.* (1979), table 3, p. 192
Columns (11) and (12)	Kiba, *et al.* (1994), table 1-2, p. 25
Columns (13) and (14)	This study

4.2 Internationalization of Research and Development

The literature supports observations that there are differences in the location and motivation of Research and Development. Most of these studies focus on the R&D activities of large multinationals since they are responsible for most of the world's R&D. Surveys and interviews with R&D managers are commonly used methods. Many of these studies compare a subset of Development that includes adapting products and processes to local markets to creation of new products, which is Applied Research.

In an early study of the internationalization of R&D, Ronstadt (1978) studied seven US multinationals and classified their 55 overseas R&D labs corresponding to the research-development distinction. Most overseas R&D units are created (42 out of 55) to transfer technology from the US parent to the foreign subsidiary and provide technical services for foreign customers (31 out of 42), which is considered development. Among R&D units that are acquired, 7 of the 13 develop new products for foreign markets using their own technological capability. Very few overseas labs perform basic research. Those are created after managers felt they needed to conduct long term exploratory research to protect their competitiveness and the sought-after foreign scientists would not move to the U.S. In contrast, the motives for setting up units to adapt technology or develop new products are to follow production and to tap growing markets.

Extending this research, Gassmann and von Zedtwitz (2002) survey 81 technology intensive multinationals and their 1021 R&D sites worldwide. They define research as discovering new scientific knowledge without the expectation of commercial value, and development as creating new products or processes with commercial prospects by applying existing knowledge. Foreign R&D investment is more than twice as likely to be development oriented than domestic R&D investment. Research is heavily concentrated in the U.S., Europe, Japan, Hong Kong, Singapore, South Korea, and Taiwan, and of the 299 research labs surveyed, only 19 were elsewhere. Development labs are more numerous (722 labs) and dispersed, with sites in southeast Asia, Australia, Africa, and South America as well. There are relatively few cases of research being more dispersed than development. Typically, a company internationalizes development first, then research.

The different motivations of research and development explain differences in where those activities are located. Kuemmerle (1999) distinguishes between home base exploiting (HBE) units, which transfer the firm's existing technology overseas, and home base augmenting (HBA) units, which create new scientific knowledge using host country resources. This is comparable to development and research. In a study of the labs of 32 multinationals in electronics and pharmaceuticals, Kuemmerle finds that HBE labs are located close to existing markets and factories while HBA labs are near universities. Further examining the locations of the labs, Kuemmerle (1999) estimates a logistic regression on the determinants of establishing HBE vs. HBA labs. The results indicate that a firm's propensity to invest in HBA activities increases with the relative commitment to R&D in the target country, the educational attainment of the labor pool, and the level of scientific achievement. The propensity to invest in HBE activities increases with the size of the host country market. This sample is limited to firms in electronics and pharmaceuticals, but Gassmann and von Zedtwitz (2002) report similar results using a broader sample. Companies do not necessarily locate research and development together because of the different nature of science and engineering. Reasons to decentralize research include proximity to universities and centers of innovation, access to science communities, and a limited domestic science base. This contrasts with the drivers of development, which are local markets and proximity to customers and producers.

Within a firm, the parent and subsidiaries confirm a divide between research and development activities exists. Surveys of the parent R&D lab of 245 large international companies show that basic research is relatively less important in overseas R&D units than at home (Pearce 1997). Improving existing products and/or techniques is equally important at home and overseas and compared to the other R&D activities, is the most prevalent overseas. This corresponds with parent labs citing the need to adapt products to the local market as a relevant factor in performing R&D abroad. However, results from a similar survey sent to the overseas R&D units show that few overseas labs view themselves as support labs that adapt existing products and processes to the local market. Instead, most describe themselves as what Pearce defines as locally integrated or internationally interdependent labs. Locally integrated labs have close links to the company's other operations in the country and develop products for the regional market. Internationally interdependent labs (IILs) have limited ties to the MNE's other functions in the same country but are connected to other R&D labs in other countries.

Pearce posits this organizational style allows them to carry out basic research. The data shows that of labs conducting basic research, almost all identified themselves as IILs, and 29.1% of IILs did basic research regularly.

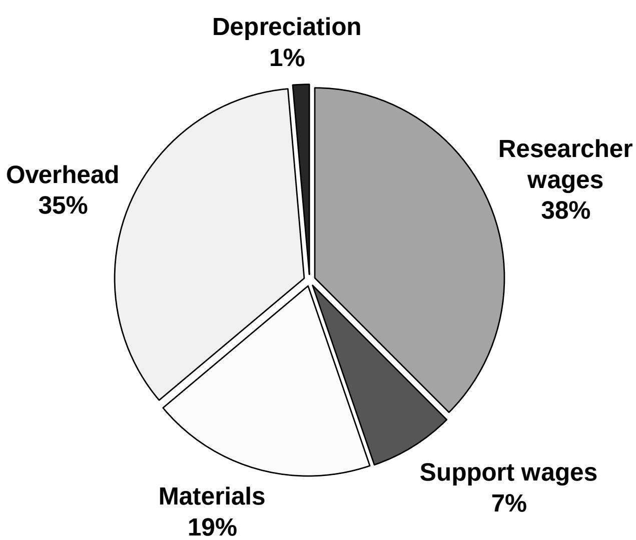
Creating new products for the local market in overseas labs is growing in importance and is discussed in several studies. Unlike basic research, which still tends to be done at home, applied research to find new products appears to be spreading around the world. Ronstadt (1978) found that over time, labs adapting technology changed to developing new products and processes for the foreign national or regional market, which falls under applied research. Because of the limited sample (labs belonging to 7 US multinationals in 1974), it is unclear if the conclusions are still valid. However, Kuemmerle (1999) does not find evidence that labs change their focus over time. He attributes this to the differences in how and why HBA and HBE labs were set up. Pearce (1999) surveys production subsidiaries and labs of foreign multinationals operating in the United Kingdom. The production subsidiaries' cite their own R&D units as an important source of technology, which shows that they are not merely adapting technology from the parent. From this, he concludes that overseas labs have evolved from adapting technology to generating their own. Although the companies surveyed are not the same, in an earlier study Pearce (1997) found that that while adapting products to the local market influences overseas R&D, creating new products and processes for the local or regional market is commonly done abroad.

5. Development of R&D and Output PPPs

This section is organized as follows: First we present data for R&D expenditures in manufacturing for six countries, Germany, France, the U.K., the Netherlands, Japan and the U.S. Then we develop measures of differences in cost composition of R&D across countries. Next we deal with the calculation and sensitivity of the R&D PPPs. After that, we present the output PPPs.

The first step in comparing the cost of R&D across countries and industries is to look at the basic components (cost shares) that make up total R&D expenditure. Figure 5-1 illustrates the estimated breakdown in R&D expenditures for the U.S. Information on wages of scientists and engineers and support personnel, materials, other current costs, and capital depreciation are available. However, due to inconsistencies in international R&D surveys, only use a subset of these categories, wages, other current costs, and depreciation can be used for comparisons.

Figure 5-1, Cost Shares for R&D in U.S. Manufacturing (1997)



5.1 R&D personnel and labor cost data

In most countries, the R&D surveys ask firms to report their total number of R&D personnel and three subcategories: Research Scientists and Engineers (RSE); Technicians (Research Assistants) and Support Personnel. In the U.S., however, the National Science Foundation (NSF) only collects data on the number of RSEs. This leads to difficulties in comparing the cost of doing R&D, especially because in the U.S. the R&D labor cost implicitly refers to all R&D personnel (thus including technicians and support). Up until 1975, the NSF separately asked for the labor cost associated with RSEs and the support personnel. However, this practice was discontinued.

This leads to three questions:

1. How do firms treat the technicians when responding to the R&D survey? And, more generally, what type of personnel is included in the support category?
2. How much support personnel is employed in addition to the staff that performs research, the S&Es and the technicians?
3. What is the unit of measurement for R&D personnel?

5.1.1 Technicians

Interviews with firms so far suggest that there is not a major distinction between technicians and RSEs. Distinctions are usually only made between those staff members that work directly on R&D projects from those that do not. The latter group is basically overhead labor and consists of administrative support, R&D managers, finance and human resources, etc. This observation suggests that the figures reported as RSE likely include technicians as well.

We also have quantitative findings that are confirmatory. If a labor PPP is calculated on the basis of scientists and engineers in both the Netherlands and the U.S., the resulting PPP is implausibly high. (The level of detail in the Netherlands R&D survey makes this comparison possible.) The labor cost level in the Netherlands would be more than twice as high as in the U.S. If, however, we also include the technician category with scientists and engineers, the relative labor cost level in the Netherlands is much closer to that in the U.S. (about 90% of the U.S. level). This makes it more plausible that RSE includes all personnel engaged in research.

5.1.2 Support personnel

The proportion of support personnel in the U.S. is much harder to determine. The data from the 1975 R&D survey suggests that firms spend about 35% of their R&D wages on support personnel. However, with the advent of PCs, and the subsequent restructuring and reorganization in U.S. manufacturing this number has probably been reduced. And even if this percentage were still correct, it would not tell us the share of support staff in total personnel.

The initial results from our firm interviews suggest a much lower percentage, between 10-25% and on average 16%. This is based on headcount data for five U.S. firms that supplied these figures. The exception to this ranking is a dedicated R&D firm, which has a support staff around 35% of total. In a sense, this figure gives a better picture of how much support is needed in total, since for R&D labs, a part of the support services, like those of headquarters they receive may not be attributed to R&D as a direct cost. We observed this in the case of many of the dedicated R&D laboratories we interviewed. Also, some support services, like IT support, may be outsourced. Then these costs would show up as overhead instead of labor cost. But what we really want is a consistent internationally comparable share.

Data on the support staff from the R&D surveys of other countries put the percentage between 15-25%. Also, we can track the support percentage for these countries for total manufacturing since the early 1980s. In all countries, the support percentage dropped during this period. The most dramatic example is the Netherlands, which had a support percentage of 30% in 1981. By 1989, it had dropped to 16% and from there on it stayed in this range. In the 1997 Economic Census, there is also information on the occupation of personnel in R&D establishments (separate R&D labs). The share of workers engaged in R&D to total employment in R&D establishments is about 80%. By deduction, this implies a support percentage of about 20%.[10] However, since this is on an establishment basis (and the R&D survey is on a firm basis), the support services from corporate headquarters will not be included in these figures.

We also have Occupational Employment and Wage Estimates by industry from the U.S. Bureau of Labor Statistics (1997). In manufacturing industries, clerical and administrative support makes up between 7% and 11% of total employment. If we include managerial and administrative personnel, the percentage rises to between 12% and 20%. Including these seems reasonable, based on our interviews. The firms we have talked to consider all personnel not directly involved in R&D projects to be part of support, so this includes the R&D managers.

[10] The number of R&D workers in R&D establishments make up about 20% of total RSEs, as given by the NSF R&D Survey. So the 20% support personnel is applicable to a sizable part of the R&D performed in the U.S.

The occupational wage and employment data also allow us to make a direct estimate of wages of RSEs and support staff. If we have average scientists and engineers' wages, we can calculate the wage sum of RSEs. We therefore use the occupational employment and wage data to get the number of persons and their wage in over 200 occupations by 2- and 3-digit SIC industry (BLS, 1997). The first step is to calculate the average wage for a scientist or engineer.[11] This allows us to estimate how much of the total labor cost is spent on this group of R&D workers.[12] By inference, the remainder is then spent on support personnel. The wage for this group (which we assume to consist of both managerial & administrative and clerical & administrative support) is then used to estimate the number of support personnel:

$$w_T T = w_{S\&E} S\&E + w_{Sup} Sup \qquad (1)$$

In equation (1), w_i is the wage of group *i*. From the R&D survey, we have information on the total wage sum $w_T T$ and on the number of RSEs. From the occupational wage data, we estimate $w_{S\&E}$ and w_{Sup}. Calculation of the total number of R&D personnel *T* is then straightforward.

We had to adjust the wage data to include bonuses (using Watson Wyatt (1998)), because the Occupational Employment Survey only asks for the base pay. The Table shows the support percentage based on a variety of assumptions, which seem plausible based on what we were told in interviews.

Support staff as a percentage of total personnel under various assumptions

	Support	
	Assumption 1	Assumption 2
Researchers, scientists and engineers		
Assumption A	25.2%	25.5%
Assumption B	31.3%	15.7%

Assumption A: researchers do not include technicians
Assumption B: researcher do include technicians
Assumption 1: support consists of both managers and secretarial workers
Assumtpion 2: support consists only of managerial support

[11] For the calculation of the average wage, we included two technician occupations as well, for the above-mentioned reasons.
[12] For transport equipment, this leads to the implausible result that the wage sum for S&E was higher than the total labor cost. Here we assumed that the wage is equal to that in total manufacturing.

Above, we argued that technicians would likely be included with other researchers, but this is not necessarily the case. Also, most interviews suggest very lean organizations with little or no administrative support in the form of secretaries and such. We would however argue that most managers within R&D would be classified as support staff, since they do not actually do (much) research. These assumptions together define a fairly broad range over which the support percentage can vary. Furthermore, this range includes the 16.1% we use to calculate the R&D PPPs in the main text. The sensitivity to various assumptions, in particular, argues against using these data for our support estimates.

Another approach to the problem can be taken through international wage surveys. The "Global Remuneration Planning Report" by Watson Wyatt (1998) supplies data on comparable pay grades and the occupations that fall in such a pay grade economy-wide. This allows us to directly calculate PPPs for each of the categories of R&D workers and compare these to the labor PPPs we used above. We do this for both scientists and engineers and support personnel and use the support percentages to come up with an overall R&D labor PPP. If we exclude an inconsistent outlier from the data, the resulting labor PPPs are generally closer to the labor PPP using the lower support estimate than that based on the high support estimate for the U.S. If we include the outlier, the high support estimate results in an implausibly high relative labor cost level of each country relative to the U.S.

Finally, we can also look at data on occupational employment from the ILO. This refers to aggregate employment in several broad employment categories. If we calculate the support percentage based on a narrow definition, including only clerical workers, the support percentages are broadly comparable to those found based on the international R&D surveys. A broader definition, including administrative personnel and managers (but even legislators) puts the support percentage of around 30% of total employment. The narrow definition seems more comparable to our R&D support figures so this once again suggests that the low support figure in the U.S. (around 15-20%) is the most plausible.

Overall, it is not entirely clear which support percentage is 'better'. If we are interested in asking how much support staff is needed to run an R&D lab, then the information from the independent R&D firm is the most useful. The support staff within the R&D industry may be a good proxy as well. However, from the perspective of international comparability, this is probably not the best answer. Since most R&D is done within a larger firm, there are always going to be hidden support costs and the extent of this is hard, if not impossible to disentangle. For this purpose, the support percentage from firm interviews or those derived from industry estimates are probably more applicable. Also, since support percentages have dropped considerably over time in the other countries, we can expect that a similar shift has taken place in the U.S. over this period. We have therefore chosen to apply the (lower) industry-wise support percentages for the U.S. from the Occupational Employment and Wage Estimates (BLS, 1997).

5.1.3 The unit of measurement for R&D personnel; head count versus FTE

One other issue with R&D personnel is that the R&D surveys collect data on the number of full-time equivalent (FTE) workers. This is in line with the Frascati Manual's recommendations. The motivation is that a significant part of R&D personnel also has functions outside of R&D. These workers should not be fully counted as R&D personnel, nor should they be excluded. The FTE measure allows a more exact allocation of work time to R&D. The exception, however, is Japan, which reports on the number of persons employed in R&D, which is likely to include persons that are only part-time employed in the R&D operation. We should therefore strive to adjust our figures to a full hours-worked measure. In NSF (1998b) a 30% downward adjustment was made based on studies by Japanese authorities, but the exact basis for these rather large adjustments is not immediately clear. This is something we will be taking up in the remainder of the project. We may be able to make some adjustment based on the number of hours worked.

5.2 Materials and supplies costs

In the U.S. and Japan, the R&D survey asks separately for the expenditure on materials and supplies and other current expenditure. This was also the case in the U.K., but only up to 1992. In the other countries materials and supplies is a part of 'other current' expenditure. While the distinction between these categories would be useful, since it is not available for all countries, we cannot use it.

5.3 Capital expenditure versus capital depreciation costs

Since 1998, the NSF has included a cost category in the U.S. R&D Survey, namely 'R&D Depreciation,' which is intended to reflect depreciation on capital (assets) related to R&D. In the other countries, firms report on capital expenditure. If capital expenditure were to remain constant over time, capital expenditure and depreciation will be equal. However, if capital expenditure rises over time, depreciation will be lower. In Japan, capital depreciation is collected as well. For 1997, 22 of the 26 industries had a higher capital expenditure than depreciation figure. On average, capital expenditure was 25% higher than depreciation. This suggests that in practice there may be important differences between the two measures. For the moment, we have simply assumed that capital depreciation in the U.S. is comparable to capital expenditure in the other countries. However, this means that when we calculate the R&D PPPs, the weight on the capital PPP is likely to be understated. One way to partly correct for this situation would be to apply the Japanese ratio of capital expenditure to depreciation (averaged over a number of years) to U.S. capital depreciation. This ratio can also be adjusted for differences between both countries in the growth rate of total R&D expenditure. So far, we have not implemented these options.

As mentioned above, the dividing line between these expenditure categories will differ across countries, depending on accounting rules. Since we have interviewed mostly U.S. and Japanese companies so far, our knowledge about these differences is incomplete so far. We do know that most purchases in the U.S. are expensed since R&D expenditure does not directly contribute to revenue. According to the FASB rules, no depreciation can then be charged. If we look at the cost shares, the U.S. capital share is much lower than the capital share in most other countries (just 1.3% for overall manufacturing in the U.S. versus 6-12% in the other countries).

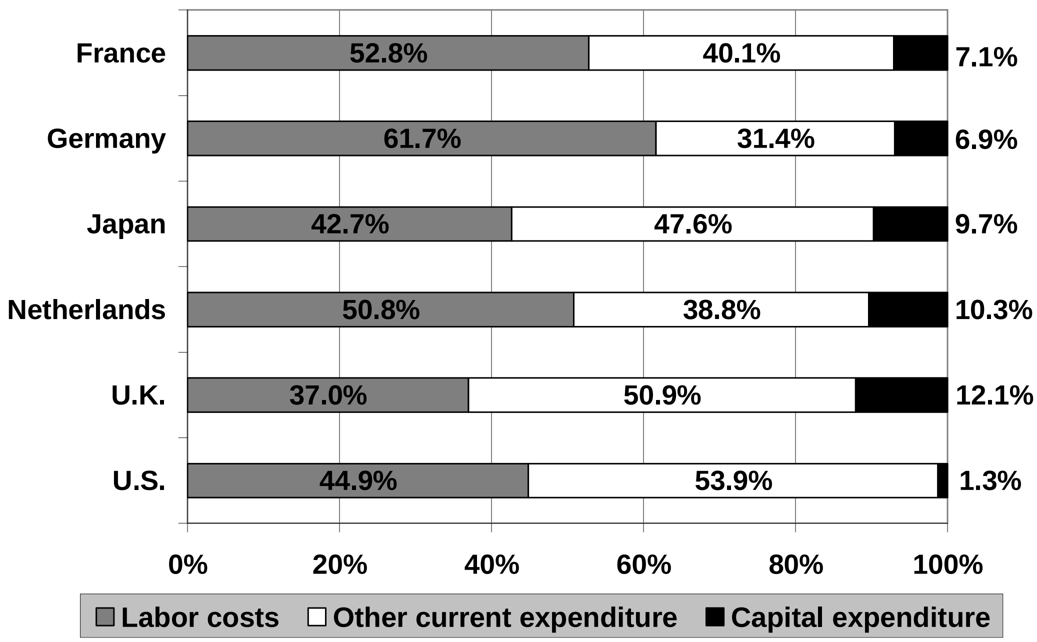
This could partly be caused by the fact that capital depreciation understates capital expenditure if capital expenditure rises over time. However, the Japanese evidence suggests that this could add 25% to capital depreciation under analogous circumstances, which still leaves the U.S. with much lower capital expenditure than the other countries. Part of the difference may come from different business practices. For example, if the firm owns the building in which R&D is performed, then it will be a capital expenditure. If on the other hand the building is leased, the rent will show up as a current cost. Interviews have suggested that this treatment is often different depending on countries and corporate policy. Accounting rules may also be important. If a piece of equipment can only be capitalized if it directly contributes to revenue, as in the U.S., certain R&D equipment will be expensed instead. Still, the figures seem to be too low. Interview responses have put capital depreciation much closer to the international average.

Another possibility is that firms interpret the question on R&D depreciation in a different way than firms in other countries interpret capital expenditure. When we asked firms how large their R&D depreciation was, some interpreted this as a question whether they capitalize R&D expenditure. In most cases, this would only be possible if software developed by R&D was also going to be sold. In that case, R&D expenditure can be classified as an investment. This ambiguity may lead to underreporting of capital depreciation.

5.4 International Cost Shares

As the above discussion makes clear, due to inconsistencies in international R&D surveys, only a subset of these categories (wages, other current costs, and depreciation) can be used for comparisons. Figure 5-2 shows how each of these three cost categories differs across countries.[13]

Figure 5-2, R&D Cost Shares in Total Manufacturing (1997)



In Germany, France and the Netherlands, labor makes up to majority of costs. In the other three countries, labor still accounts for around 40% of the costs. The other major category is

[13] Information from firm interviews, while showing large variations, both between firms and between the firms and the survey data in costs. However, the differences between firms and the survey data are generally in predictable directions (i.e. often attributable to a focus on labor-intensive research or capital-intensive development), and are consistent with the inference that the survey data are consistent with the "average" firm's situation.

‘other current expenditure’, which includes materials and supplies, office rent, overhead, etc. Capital expenditure is a small fraction of total R&D costs ranging from 1.3% in the U.S. to 12% in the U.K.[14] However, these cost shares for overall manufacturing hide a wide variety of cost structures within industries.

Table 5-1 gives an overview of the share of labor cost in total manufacturing. While labor costs make up around half of the cost of R&D in manufacturing, this share is considerably higher in fabricated metal products but quite a bit lower in petroleum and coal products. Also, while the labor share in U.K. manufacturing is the lowest of all the countries, in some industries the labor share is actually above the country average (like in basic metal products). This suggests that if we would only use an R&D PPP for total manufacturing, the results would be biased when applied to individual industries.

However, the cost share are but a first step in estimating the cost differences across countries. The next step is to find a good relative price for each of the three cost categories, so we can calculate our R&D PPPs.

Table 5-1, The share of labor cost in industry R&D expenditure

	France	Germany	Japan	Netherlands	U.K.	U.S.	Average
Food and kindred products	54.6%	62.4%	54.8%	62.8%	51.7%	48.3%	55.7%
Textiles, wearing and leather products	56.4%	62.1%	48.7%	57.1%	54.5%	51.4%	55.1%
Wood, paper products, printing & publishing	56.5%	56.7%	50.2%	76.6%	31.8%	52.2%	54.0%
Chemicals & allied products	51.7%	56.5%	48.6%	49.4%	32.8%	43.2%	47.1%
Petroleum & coal products	50.2%	56.5%	47.5%	37.5%	32.4%	43.3%	44.6%
Rubber and plastic products	49.8%	56.5%	49.8%	59.6%	41.7%	48.4%	51.0%
Non-metallic mineral products	55.2%	63.3%	45.9%		46.8%	39.7%	50.2%
Basic metal products	57.6%	62.3%	41.2%	48.0%	55.6%	57.4%	53.7%
Fabricated metal products	62.3%	62.2%	54.8%	72.0%	38.6%	52.0%	57.0%
Machinery & equipment	63.1%	65.9%	48.4%	53.6%	44.5%	47.0%	53.7%
Transport equipment	48.3%	61.8%	37.5%	58.0%	34.9%	38.7%	46.5%
Electrical machinery and instruments	55.1%	64.4%	39.2%	47.6%	42.0%	47.4%	49.3%
Furniture and miscellaneous manufacturing	56.0%	68.0%	47.3%		32.0%	79.5%	56.6%
Total manufacturing	52.8%	61.7%	42.7%	50.8%	37.0%	44.9%	48.3%

[14] In the U.S., capital expenditure is not collected, so we report capital depreciation.

5.5 Construction of R&D PPPs

This section is devoted to the calculation of R&D PPPs for each of the manufacturing industries. We will briefly cover the calculation of a PPP for each of the major cost categories and the resulting R&D PPPs. The sensitivity of the results to several different assumptions will also be considered.

5.5.1 Labor

In order to calculate a PPP for labor for each of the industries in the five countries relative to the United States we need the average wage for an R&D worker. The simplest way to get these wages is to divide the R&D labor cost by the total number of R&D personnel. This can be done on the basis of the national R&D surveys for all countries except the U.S. In the U.S., the National Science Foundation (NSF) only collects data on the number of researchers, scientists and engineers (RSEs) while R&D labs also employ a considerable number of support staff.[15] We therefore need to supplement our data from the NSF Survey with additional data on wages and personnel.

While we have not found a completely satisfactory way to estimate a total R&D personnel figure for the U.S., we use the 16.1% estimate shown in Table 5-2 based on the percentage of support staff for an industry as a whole. While there is no guarantee that the R&D operation needs the same amount of support staff as the rest of an industry, our estimate looks reasonable compared to other countries. Our firm interviews also give us corroborating evidence that this approach probably gives a good representation of the support share of R&D labor in the U.S. in comparison to other countries.

Table 5-2, The ratio of support staff to total R&D personnel in manufacturing (1997)

France	15.4%
Germany	26.8%
Japan	20.4%
Netherlands	16.1%
U.K.	17.5%
U.S.	16.1%

Sources: OECD “BERD Database”, NSF “Science and Engineering Indicators 2000” and BLS “Occupational Employment and Wage Estimates, 1997”

[15] Formally, in the U.S. as well as in the other countries, the number of full-time equivalent R&D workers is collected instead of the absolute number. See appendix A1 for more details.

We can now calculate labor PPPs simply as the labor cost per person in a country relative to the U.S. If we divide those PPPs by the exchange rate, we get the relative cost of employing an R&D worker in a country compared to the U.S. Table 5-3 shows these cost levels for manufacturing as a whole.

These estimates show that for France and Japan, the labor cost per scientist is comparable to the U.S. Only the U.K. appears to be much cheaper at 72.7%. At the other end of the scale, Germany is nearly 15% more expensive. These findings stand in contrast to that of earlier studies that found R&D labor costs to be significantly lower overseas, as shown in Section 5 and Table 5-1.[16] This is probably a result of rising average wages in Europe and Japan relative to the U.S., but may also be reflective of increasing international mobility of scientists.

Table 5-3, Relative cost level of R&D workers (as % of the U.S.) in manufacturing

France	99.7%
Germany	114.4%
Japan	103.6%
Netherlands	88.4%
U.K.	72.7%
U.S.	100.0%

5.5.2 Other current expenditure and capital expenditure

With labor, we have nearly half the story. The remainder consists of the other current and capital components of R&D expenditure. For the labor cost component, we had industry-specific data. This is not the case for the other two cost categories. We do however, have a reasonably good idea of what costs are classified as ‘other current expenditure’ or ‘capital expenditure’ based on the firm interviews and R&D survey instructions. In the ‘other current expenditure’ category we find costs like rent, electricity, computers, travel and living expenses, etc. Capital expenditure includes lands, buildings, instruments, computers, etc. These categories have been selected largely on the basis of interviews with U.S. and Japanese firms. While we have not

[16] Of course, one could argue that scientists, especially top scientists, are geographically very mobile.

included an exhaustive inventory of categories, we have selected those that firms most often mention as important non-labor costs.

For each of the major cost categories, we select a PPP, which should most closely give the relative price for that item. The PPPs are either ICP expenditure PPPs or ICOP industry-of-origin PPPs. For most manufacturing goods, like (electrical) machinery, we rely on ICOP PPPs, since these are based on all goods that are produced in that industry, instead of only on the goods that are used for final consumption (van Ark, 1993). For other cost categories, like rent, intermediate goods are not an issue and we rely on ICP PPPs (Kravis et al., 1982).. The final PPPs for other current expenditure and for capital expenditure are then based on unweighted averages of the various PPPs. The selection and aggregation of these PPPs was based on information gathered in interviews and from national R&D survey forms.

If we compare the items that make up the costs in the other current expenditure and capital expenditure category, there is some overlap. For example, computers are included in both. This ambiguity largely depends on the depreciation practices a country or a firm follows. Furthermore, it also depends on the specific type of equipment. While some computers, like desktop models, may be expensed because they depreciate so fast, others like mainframes might be durable enough to be counted as a capital expenditure. The differences in Figure 2 between the U.S. and the other countries in the share of capital expenditure probably largely reflect differences in accounting practices. Using similar relative prices therefore seems justified.

The most appropriate relative prices for these costs are probably ICP expenditure PPPs or ICOP industry-of-origin PPPs. Each has their advantages and disadvantages.The ICP PPPs are based on prices of consumption and investment goods, and since they cover the entire economy, they are relatively comprehensive (Summers and Heston, 1996). But the prices are for final expenditures in GDP and do not cover intermediate goods, so they are not necessarily suited for the other current expenditure category. Yet for capital expenditure, they should be a good reflection of the relative prices. However, the Castles Report (1997) concluded that the investment PPPs were less reliable than consumption PPPs, so they need to be used cautiously. Finally, since ICP PPPs include indirect taxes, which most businesses can get refunded, these margins have to be “peeled off” (Jorgenson and Kuroda, 1992).

The advantages of the ICOP PPPs are in the areas where the ICP PPPs are weakest (Van Ark and Timmer, 2001). For example, they cover intermediate goods extensively, including most investment goods in particular. These comparisons rely upon item-level comparisons of production census information (Eurostat, 1997b). Unfortunately, lack of detailed data for some products in high-tech industries (machinery, electrical machinery and computers) and the likely heterogeneity across countries for these products weakens some of these comparisons. In addition, since ICOP PPPs are based on producer prices, we need to make an adjustment for transport and distribution margins, by adding them back in. This is because businesses buy these products as intermediate or capital inputs for the R&D process.

The Table gives an overview of the PPPs we have decided to use for both categories:

Cost categories within other current expenditure and capital expenditure

		Expenditure type	
	ICOP		
ISIC code		Other current	Capital
21-22	Printing and publishing [books]	x	
29	Industrial Machinery	x	x
30	Office, accounting and computing machinery	x	x
31-33	Electrical machinery	x	x
40-41	Electricity, gas and water	x	
50-52	Wholesale and retail trade [repairs]	x	
60-63	Transport and storage [travel cost]	x	
64	Communications (services)	x	
	ICP		
ICP code			
1131011	Rents of tenants	x	x
1131012	Imputed rents of owner-occupiers	x	x
1185011	Insurance charges (except car and health)	x	
1422012	Industrial buildings		x
1422013	Buildings for market services		x
1422014	Buildings for non-market services		x
1422021	Renovation for non-residential buildings		x

Notes: For some categories, square brackets denote some of the costs that would be captured by that category

As can be seen, these categories cover a wide range of costs. The ICP PPPs were taken from OECD (1999). Since the PPPs are for 1996, we had to update them to 1997 based on industry-specific deflators from the OECD STAN database. The ICOP PPPs are mostly based on data from the national or European production censuses. Van Ark (1993) and Van Ark and Timmer (2001) contains a discussion on the methodology. The transport, communication and trade PPPs are based on Van Ark, Monnikhof and Mulder (1999). To use these PPPs for our R&D PPPs, we make an adjustment for transport and distribution margins for the ICOP PPPs and an adjustment for indirect taxes for the ICP PPPs. The information for these adjustments was taken from the input/output (I/O) Tables.

The next step is to aggregate the different relative prices to form one PPP for other current expenditure and one PPP for capital expenditure. Ideally, we would like to have information on the cost share by industry for each of the cost categories. However, this information is not generally available, although we are currently developing it based on firm interviews for four high-tech industries. Another possibility might be to use the input structure from the I/O tables for each manufacturing industry. However, it is not likely that industry-wide input structures would reflect the inputs of R&D labs.

As an alternative, we explored the possibility of using the input structure of the R&D industry (ISIC 73) from the I/O Tables. However, we came to the conclusion that the R&D industry data from the I/O Tables are strongly influenced by the institutional setting of the country. For example, Dutch R&D firms get about 70% of their inputs from the R&D industry itself. This might be due to the dominant position of the research institute TNO that subcontracts a lot of research to other labs. Similarly, the extreme lack of consistency in the major inputs into the R&D sector suggested that they were not comparable. For instance, the educational sector make up 22.5% of output in Germany, yet less than 1% in all the other countries. Based on these considerations, we opted to simply take an unweighted average of the PPPs.[17]

Table 5-4 shows the PPPs for other current expenditure and capital expenditure as well as the 1997 exchange rate and the OECD GDP PPP. It is not clear whether these PPPs can be expected to be close to either the GDP PPP or the exchange rate, since both include traded and non-traded goods. In other current expenditure, we have included industrial machinery, which is traded, but also a PPP for building rents, a non-traded good. It is therefore not surprising that Table 5-4

[17] We also experimented with using national expenditure weights for ICP PPPs, where all ICOP PPPs were replaced by appropriate ICP PPPs. However, there are also no grounds to believe that this would be more applicable to R&D. Furthermore, it did not influence the overall results significantly.

shows a mixed picture. We can see that the cost of other current expenditure is higher than for capital in each of the countries except for the Netherlands. While some of the PPPs are reasonably close to the GDP PPP or the exchange rate, other current expenditure in Germany and Japan show PPPs that are significantly higher than both the GDP PPP and the exchange rate. The German and Japanese PPPs are likely to have a large effect on the final R&D PPP since other current expenditure makes up 31% and 47% of total R&D costs, respectively.

Table 5-4, PPPs for R&D labor, other current expenditure, capital expenditure vis-à-vis the GDP PPP and the U.S. dollar exchange rate (1997 Manufacturing)

	Labor	Other current	Capital	GDP PPP	Exchange rate
France	5.82	5.99	5.25	6.51	5.84
Germany	1.98	2.46	2.04	1.94	1.73
Japan	125	212	155	163	121
Netherlands	1.72	2.09	2.34	1.97	1.95
U.K.	0.44	0.67	0.53	0.63	0.61
U.S.	1.00	1.00	1.00	1.00	1.00

5.6 R&D PPPs and relative cost levels

The previous subsections have supplied the building blocks for our R&D PPPs. We first calculated industry-specific labor PPPs, then second calculated general PPPs for other current expenditure and capital expenditure. We can now use the industry-specific R&D cost composition data to aggregate these separate PPPs to form R&D PPPs. For this aggregation we use the cost weights of the base country, the U.S. (another countries could just as easily be used). The first weighting procedure leads to a Laspeyres PPP:

$$PPP_L^{x,u} = \sum_i w_i^{u(\$)} PPP_i \qquad (2)$$

The Laspeyres PPP is calculated as the weighted average of the three cost categories' individual PPPs: for labor, other current, and capital expenditure PPPs. The weights are the U.S. cost shares in U.S. dollars: $w_i^{u(\$)} = C_i^{u(\$)} \big/ \sum_i C_i^{u(\$)}$. We use the comparison country's cost weights to calculate a Paasche PPP:

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

where $w_i^{x(\$)} = C_i^{x(\$)} \Big/ \sum_i C_i^{x(\$)}$. This 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 (2) and (3) yields the Fisher PPP.

Table 5-5, R&D PPPs relative to the U.S. for manufacturing industries (1997)

	France	Germany	Japan	Netherlands	U.K.	U.S.
Food and kindred products	5.09	1.65	135.4	1.71	0.53	1.00
Textiles, wearing and leather products	5.21	1.88	160.2	1.80	0.46	1.00
Wood, paper products, printing & publishing	5.85	2.01	139.3	1.81	0.46	1.00
Chemicals & allied products	5.50	1.93	160.0	1.81	0.54	1.00
Petroleum & coal products	5.91	1.93	173.6	2.66	0.73	1.00
Rubber and plastic products	5.49	1.93	165.5	1.81	0.56	1.00
Non-metallic mineral products	5.98	2.11	159.5	1.92	0.52	1.00
Basic metal products	5.48	2.02	160.2	1.92	0.54	1.00
Fabricated metal products	4.98	1.74	134.2	1.44	0.41	1.00
Machinery & equipment	6.03	2.15	174.0	1.98	0.59	1.00
Transport equipment	6.94	2.91	203.3	2.17	0.67	1.00
Electrical machinery and instruments	5.39	1.81	147.2	1.73	0.47	1.00
Furniture and miscellaneous manufacturing	5.57	1.71	206.4	1.92	[a]	1.00
Total manufacturing	5.87	2.18	165.6	1.92	0.56	1.00
Average dollar exchange rate	5.84	1.73	121.0	1.95	0.61	1.00
GDP PPP	6.51	1.94	163.0	1.97	0.63	1.00

Note: The cost composition for the Netherlands is for 1996, for the U.S. it is for 1998. The PPPs for Germany for petroleum and coal products as well as for rubber and plastic products are assumed to be the same as for chemical and allied products. For the Netherlands, non-metallic mineral products and furniture and miscellaneous manufacturing are assumed equal to total manufacturing.
[a] This PPP had an extremely low value due to the fact that the personnel data is rounded to the nearest 1,000 persons. Until we have more accurate data we leave this PPP out.

Table 5-5 presents the R&D (Fisher) PPPs for the manufacturing industries. Manufacturing-wide, the PPPs for Germany and Japan are substantially higher than the exchange rate. In the other countries, they tend to be closer. In all countries, the PPPs differ significantly across industries. So while the PPP for food products is only 1.65 in Germany, the PPP for transport equipment is 2.92. As mentioned earlier in this Section, the PPPs differ across industries for two reasons. First of all, we have a different labor PPP for each industry. Second, the cost shares differ across industries, so the contribution of each of the labor, current expenditure, and capital PPPs varies.

Table 5-6 presents the relative cost levels of R&D and its cost components at the level of manufacturing:

Table 5-6, Relative cost levels versus the U.S. of R&D, R&D labor, other current and capital expenditure in manufacturing (1997)

	R&D	Labor	Other current	Capital
France	103.1%	99.7%	102.6%	90.0%
Germany	125.8%	114.4%	142.3%	118.2%
Japan	136.9%	103.6%	174.9%	128.2%
Netherlands	94.7%	88.4%	107.2%	120.2%
U.K.	91.7%	72.7%	110.3%	87.7%
U.S.	100.0%	100.0%	100.0%	100.0%

Note: the relative cost level is calculated as the PPP over the exchange rate.

This table shows how the various components influence the final R&D cost level. As we saw in Figure 5-2, the main influences on the R&D PPP are the labor and other current expenditure PPPs. For each of the countries compared to the U.S., the relative cost of other current expenditure is higher than the labor component.

5.7 PPPs for industry output

We also compare the prices of industry output. To calculate these PPPs, we follow the ICOP approach as described in van Ark (1993), van Ark and Pilat (1993), van Ark and Timmer (2001) and others. On the basis of production censuses, unit values are used, which are defined as the ratio of product value over product quantity. The unit value ratio (UVR) for a product is then the relative price for that product. The individual UVRs are then aggregated to the industry level using equation (2) and (3), where the weights are now based on the share of the product in the industry value of shipments. Aggregation to total manufacturing is done by taking the industry UVRs and once again applying (2) and (3), where the weights are now of the share of each of the industries in the total value of shipments in manufacturing.

For the European countries, the PRODCOM database from Eurostat provides most product data from the national censuses.[18] This database provides the product data in a consistent industry classification. For the U.S., the *1997 Economic Census for Manufacturing*, supplemented by *Current Industrial Reports* from the Census Bureau provides the data. For Japan, the data is from MITI, the *Census of Manufacturers*, *Report by Commodity*. The products in each country are then matched to those in the U.S.

Table 5-7, PPPs for industry output relative to the U.S. for manufacturing industries (1997)

	France	Germany	Japan	Netherlands	U.K.	U.S.
Food and kindred products	7.70	1.71	247.2	2.06	0.81	1.00
Textiles, wearing and leather products	9.68	2.95	168.7	2.22	0.81	1.00
Wood, paper products, printing & publishing	6.36	1.65	158.9	1.73	0.77	1.00
Chemicals & allied products	5.96	1.83	167.1	1.73	0.72	1.00
Petroleum & coal products	5.96	1.83	265.2	1.73	0.72	1.00
Rubber and plastic products	5.03	1.87	114.6	1.50	0.75	1.00
Non-metallic mineral products	5.16	1.26	126.7	2.28	0.84	1.00
Basic metal products	4.89	1.66	129.8	2.33	0.77	1.00
Fabricated metal products	5.35	1.51	176.8	0.99	0.50	1.00
Machinery & equipment	4.01	1.98	153.2	1.41	0.56	1.00
Transport equipment	4.91	2.18	111.3	2.46	0.61	1.00
Electrical machinery and instruments	4.50	1.98	98.7	2.21	0.78	1.00
Furniture and miscellaneous manufacturing	6.46	2.18	152.0	2.80	0.66	1.00
Total manufacturing	5.59	1.84	152.0	2.10	0.67	1.00
Average dollar exchange rate	5.84	1.73	121.0	1.95	0.61	1.00
GDP PPP	6.51	1.94	163.0	1.97	0.63	1.00

[18] There are exceptions. For example, NACE 23 (Petroleum and coal products) is not covered yet. Also, in some countries like Germany, lager product detail is available in national statistics. In the German case, this extra product detail was used.

We next aggregate all UVRs to the industry and total manufacturing level. Table 5-7 shows the resulting (Fisher) PPPs. Unlike in the case of the R&D PPPs, the output PPPs are generally much closer to the dollar exchange rate. For France, the manufacturing PPP is even below the exchange rate. Still, the variation across industries is fairly large. So while the German manufacturing PPP is only 1.84 (6% above the exchange rate), the PPP for textiles, wearing apparel and leather is 2.95 (71% higher) and fabricated metal products only 1.51 (13% lower).

Finally, Table 5-8 slows the ratio of the R&D PPP to the output PPP by industry. These ratios are used to adjust R&D intensity measures in Section 6. The wide deviations from unity in the Table (which would indicate each PPP is the same) demonstrate the importance of adjusting R&D and output expenditures separately.

Table 5-8, R&D PPPs relative to industry output PPPs for manufacturing industries (1997)

	France	Germany	Japan	Netherlands	U.K.	U.S.
Food and kindred products	0.66	0.97	0.55	0.83	0.65	1.00
Textiles, wearing and leather products	0.54	0.64	0.95	0.81	0.56	1.00
Wood, paper products, printing & publishing	0.92	1.22	0.88	1.05	0.60	1.00
Chemicals & allied products	0.92	1.05	0.96	1.05	0.75	1.00
Petroleum & coal products	0.99	1.05	0.65	1.54	1.00	1.00
Rubber and plastic products	1.09	1.03	1.44	1.21	0.74	1.00
Non-metallic mineral products	1.16	1.68	1.26	0.84	0.61	1.00
Basic metal products	1.12	1.22	1.23	0.82	0.70	1.00
Fabricated metal products	0.93	1.15	0.76	1.45	0.83	1.00
Machinery & equipment	1.50	1.09	1.14	1.41	1.06	1.00
Transport equipment	1.41	1.34	1.83	0.89	1.08	1.00
Electrical machinery nec and instruments	1.20	0.92	1.49	0.78	0.60	1.00
Furniture and miscellaneous manufacturing	0.86	0.79	1.36	0.68		1.00
Total manufacturing	1.05	1.18	1.09	0.91	0.83	1.00

6. Impact on R&D Intensity Measures

A good start in comparing R&D across industries and countries is to look at R&D intensities. These intensities are the R&D expenditure as a percentage of industry gross output. They give an indication of how much of their output firms in an industry sacrifice to do R&D. Table 6-1 shows R&D intensity in 13 major manufacturing industries as well as for manufacturing as a whole based on published OECD figures.

Table 6-1, R&D intensity in manufacturing industries as % of gross output (1997)

	France	Germany	Japan	Netherlands	U.K.	U.S.	Average	Coef. of var.
Food and kindred products	0.31	0.14	0.67	0.50	0.24	0.36	0.37	0.51
Textiles, wearing and leather products	0.42	0.62	0.86	0.47	0.16	0.30	0.47	0.52
Wood, paper products, printing & publishing	0.16	0.14	0.33	0.14	0.10	0.33	0.20	0.52
Chemicals & allied products	4.36	4.56	6.55	3.05	6.11	4.64	4.88	0.26
Petroleum & coal products	4.36	0.13	0.73	0.40	1.46	0.94	1.34	1.16
Rubber and plastic products	1.89	1.03	1.82	1.10	0.30	0.90	1.17	0.51
Non-metallic mineral products	1.22	0.67	2.11	1.87	0.41	0.81	1.18	0.58
Basic metal products	1.13	0.52	1.75	1.14	0.30	0.46	0.88	0.62
Fabricated metal products	0.67	0.65	0.74	0.50	0.36	0.78	0.62	0.25
Machinery & equipment	2.26	2.36	2.91	2.49	1.83	7.32	3.20	0.64
Transport equipment	3.98	5.11	3.49	1.63	3.37	3.49	3.51	0.32
Electrical machinery nec and instruments	6.52	5.38	5.89	7.98	2.93	5.90	5.77	0.29
Furniture and fixtures and misc. manufacturing	0.95	0.27	1.75	1.87	0.17	1.82	1.14	0.69
Total manufacturing	2.64	2.40	3.04	1.87	1.75	2.61	2.38	0.21
Coef. of variation	0.92	1.21	0.87	1.16	1.32	1.11		
Total manufacturing (as % of value added)	9.83	5.29	7.54	6.58	4.13	5.32	6.45	0.32

Note: R&D intensity is defined as R&D expenditure as a percentage of gross output in current prices. The coefficient of variation is the standard deviation over the average. Sources: OECD (2001) “BERD Database”, NSF (2000) “Science and Engineering Indicators”, Eurostat (1997) “Panorama of European Business”, Statistisches Bundesamt “Produzierendes Gewerbs”, CBS “Samenvattend Overzicht van de Nederlandse Industrie”, METI “Census of Manufacturers, Report by Enterprises” and U.S. Census Bureau “1997 Economic Census”

There is a very wide range of R&D intensities across industries. In some industries, like chemicals (which includes pharmaceuticals), electrical machinery (computers, telecom equipment) and transport equipment (automobiles), R&D intensity lies between 5-10%. In other industries like food or wood, paper and printing, intensity is always below 1% and (most of the time) even below 0.5%. This wide diversity of intensities shows up as a coefficient of variation across industries that is mostly greater than 1. The variation in Japan is relatively low, with reasonably high intensities in almost all industries. The spread in the U.K. is highest, since R&D is high in the above-mentioned high-tech industries, but mostly lower than 0.5% in all the other industries. In contrast to the high industry variation, the variation across countries is relatively small. R&D intensity in the chemicals industry lies between 3% and 7%, while in the wood, paper and printing industry it lies between 0.1% and 0.4%. This suggests that similar technological opportunities do matter, but that they do not explain all cross-country differences.

One of these differences is that R&D costs and industry prices differ across industries and countries. So a higher R&D intensity can also reflect higher cost of R&D or lower prices of output. If we calculate R&D intensities that adjust for these differences, we get a measure of the quantity of R&D inputs to the quantity of output. This figure gives us the *real* investment in R&D to the real output, instead of the (nominal) expenditure.

Table 6-2, R&D intensities adjusted for price and cost differences

	France	Germany	Japan	Netherlands	U.K.	U.S.	Average	Coef. of var.
Food and kindred products	0.48	0.15	1.22	0.61	0.36	0.36	0.53	0.70
Textiles, wearing and leather products	0.77	0.98	0.91	0.58	0.29	0.30	0.64	0.47
Wood, paper products, printing & publishing	0.18	0.11	0.37	0.14	0.16	0.33	0.22	0.51
Chemicals & allied products	4.72	4.33	6.84	2.91	8.15	4.64	5.26	0.36
Petroleum & coal products	4.72	0.13	1.11	0.26	1.46	0.94	1.43	1.18
Rubber and plastic products	1.73	1.00	1.26	0.91	0.40	0.90	1.04	0.43
Non-metallic mineral products	1.05	0.40	1.67	2.05	0.67	0.81	1.11	0.57
Basic metal products	1.00	0.43	1.41	1.39	0.44	0.46	0.85	0.56
Fabricated metal products	0.72	0.57	0.98	0.35	0.44	0.78	0.64	0.37
Machinery & equipment	1.50	2.17	2.56	1.76	1.73	7.32	2.84	0.78
Transport equipment	2.81	3.83	1.91	1.85	3.11	3.49	2.83	0.29
Electrical machinery nec and instruments	5.44	5.88	3.95	10.19	4.89	5.90	6.04	0.36
Furniture and fixtures and misc. manufacturing	1.10	0.34	1.28	2.05	a)	1.82	1.17	0.60
Total manufacturing	2.51	2.03	2.79	2.05	2.10	2.61	2.35	0.14
Coef. of variation	0.89	1.22	0.87	1.36	1.37	1.11		
Total manufacturing (as % of value added)	9.36	4.47	6.92	7.21	4.97	5.32	6.37	0.29

Note: Adjustments to industry R&D intensities are calculated by dividing R&D in dollars by output in dollars. R&D in dollars is calculated as the R&D expenditure in national currency divided by the relevant R&D PPP. Output in dollars is calculated analogously. [(a)] See note (a) under Table 5-5.

Table 6-2 shows such 'real' R&D intensities. These figures show that for manufacturing as a whole, the R&D investment ratios are more similar than in the unadjusted case. For example, in the U.K. the R&D intensity was only 1.75% of gross output, but if we take into account that R&D labor is cheaper in the U.K., while output prices are similar, they are actually making investments more comparable to those in other countries (2.10%). In other cases, R&D intensities moved away from the cross-country average. For example, this is the case for electrical machinery in the Netherlands. The unadjusted R&D intensity was already high at 7.98%, but our adjustments raised it even further to 10.19%. If we look at the coefficients of variation, these have increased for six of the industries, while they have decreased for seven, as well as for manufacturing as a whole.

We would like to know how much of the difference between Tables 6-1 and 6-2 is due to differences in R&D input costs and how much is due to differences in industry output prices. We make this assessment by looking at the R&D intensities before and after cost and/or price adjustments. The comparison we make is relative to the U.S. intensity because the PPPs are calculated relative to the U.S. prices. So the question we ask is whether the difference with the U.S. becomes larger or smaller after cost and/or price adjustments have been made.

To see how much of the change in intensity is due to R&D cost adjustments and how much is due to output price adjustments, we calculate R&D intensities, which separately adjusts intensities for differences in R&D costs and output price differences.[19] Table 6-3 shows the four different R&D intensities for total manufacturing. In the case of France and Germany, the difference relative to the U.S. R&D intensity increased as a result of our overall PPP adjustments. For the other three countries, the gap decreased. In the case of the Netherlands and the U.K., both the price of R&D inputs and of industry output is lower than in the U.S., while for the other three countries, the adjustments go either way. This mixed picture emerges in quite a number of industries in all countries as well: in only half the cases do the adjustments go in the same direction. In perfect competition one would expect that if the costs of inputs were lower, then the output prices would be lower as well. The reason that this is not a general observation here is probably due to the fact that (*i*) R&D is not an internationally traded commodity like most industry outputs, and (*ii*) R&D only accounts for only a small part of total inputs.

Table 6-3, R&D intensities with cost/price adjustments for total manufacturing in 1997

[19] The cost-adjusted intensity is calculated by dividing the R&D expenditure by the relative R&D cost level (or the R&D PPP over the exchange rate). The price-adjusted intensity is calculated in a parallel fashion using the output PPPs.

	France	Germany	Japan	Netherlands	U.K.	U.S.
Unadjusted	2.64	2.40	3.04	1.87	1.75	2.61
R&D input cost adjusted	2.62	1.91	2.22	1.90	1.91	2.61
Industry output price adjusted	2.53	2.55	3.82	2.02	1.93	2.61
Cost & Price adjusted	2.51	2.03	2.79	2.05	2.10	2.61

7. Interviews of Firms

In-depth interviews of representative R&D-performing firms are used to improve the results of the analytical work and provide context for interpreting their implications. Firms with median R&D intensity and substantial R&D expenditures are selected in each of the four high-tech industries, using *Compustat Global* and *Worldscope* databases of public firm data.[20] In each country, these firms' R&D expenditure generally cover over half of the R&D performed in each industry.[21] A profile of these firms is shown in Appendix B2 and their representativeness is assessed in Appendix B3 (suppressed for confidentiality).

Each interview was conducted in person with a senior R&D executive in the firm.[22] Many of these executives were affiliated with dedicated R&D labs, and R&D was their primary responsibility. An interview guide (outline) determined the structure of the interviews, and provided a checklist of questions and issues. Interviews were conducted on site and usually took 1½ to 2 hours. After the completion of each interview, we e-mailed interviewees an agreed-upon spreadsheet form asking for detailed R&D expenditure breakdowns by country (and business unit if possible). 17 interviews have been conducted so far, 7 in Japan, 1 in the U.K., and 9 in the U.S. While some of these firms perform R&D in only one country, most have development activities outside of their home country and several have also have global research activities. So far, we have at least one firm in each of our high-tech industries for the U.S. and Japan. About half of the planned number of interviews have been conducted; European countries (and broader U.S. coverage) will be the main focus of the remaining interviews.

We used the interviews to improve the quality of the PPPs and to gauge the accuracy of information collected in the international R&D surveys. Nearly all of the interviewed companies provided R&D expenditure breakdowns.[23] In most cases, the breakdowns were provided by a

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[20] This information was supplemented with contact information from The Conference Board's internal member database, the public database *idExec* of global function-specific executives, and the American Directory of R&D Laboratories.
[21] In each industry and country, the R&D expenditures of the top several R&D performers are many times larger than other R&D performers. However, these large R&D performers' R&D intensities do not seem to be systematically higher or lower than smaller firms' are.
[22] Typical job titles are Senior VP of Research, VP of Product Development, Executive Director of R&D.
[23] One Japanese firm asserted that as a holding company it did not have the authority to disclose its individual business unit's activities.

financial or accounting specialist within the Research or Development unit we interviewed, using firms' internal expenditure categories.

7.1 Recurring Issues

A series of issues came up repeatedly in interviews, each of which has important implications for understanding the R&D process. These issues relate to the way R&D surveys are conducted, the definition of R&D, its organization within the firm, as well as measurement of inputs and outputs. Below we describe the key issues that came up during the interviews, providing context for the interpretation of our results.

R&D Survey Forms

We asked the interviewees to provide us with copies of their Annual R&D Survey (RD-1) forms or national equivalent. Only two companies were familiar with such a form; the others "had no idea" who filled it out, and had no recollection of seeing the form previously – they generally surmised that the finance staff at their headquarters completed the RD-1 survey, but they usually could still not track it down. We presume that nearly all the companies we met with complete the RD-1, since they are among the largest R&D performers in their industries. The fact that few of these executives had been consulted about the content of the form suggests that some of the information it reflects may not be accurate.

Executives also pointed out that questions that ask to separate R&D by content or purpose requires detailed knowledge of the content and scope of their activities. Respondents who are in headquarters and are not part of the R&D units would be able to provide accurate information. In any case, we were told, questions about expenditures would need to coincide with company business unit structure or accounting convention or they would only be estimated very roughly.[24]

Variations in the scope of R&D

Companies have a wide range of interpretations of the boundaries of R&D. Even among companies in the same industry, interpretations vary. For example, in pharmaceuticals, post-clinical studies are considered R&D by some firms and marketing by others. In auto

[24] One of the two R&D executives that was familiar with the RD-1 said that they had once gone to the effort to conduct an internal survey asking global R&D managers to estimate the share of their R&D expenditures going toward development. But this was a rather exceptional case.

manufacturing, engineering and testing done in the research organization is considered to be R&D by the firms we spoke with, yet some product development done outside the research organization was is not always considered to be R&D. This classification problem was common among firms both in the U.S. and Japan.

Executives were readily familiar with the SEC R&D figures their company reported, and they assumed that whoever filled out their RD-1 form used this figure precisely. Several firms were also working with consultants to clarify what qualifies as R&D under the IRS R&D tax credit. It would be useful to make the NSF R&D definition coincide exactly with an R&D definition that has tax or regulatory import to ensure that reporting of R&D expenditures on the NSF RD-1 survey is more uniform and consistent.

Distinctions between Research and Development

Research and development differ in a variety of fundamental respects across all of the firms interviewed. Research is not targeted toward a specific product or process, while development is usually focused on a clear product or process objective. This critical difference was common amongst all of the firms we spoke with, and leads to differences in expenditure, funding, internationalization, and content.

Development dominates research in terms of expenditure, by a ratio of as high as 10:1. Much of these development expenditures are funded by and located in business units, rather than the research labs. In some cases, development is not easily distinguished from many engineering and testing functions, and a number of firms focus on the concept “RDE” rather than R&D.

In contrast, research (if it is done at all in the business) is usually funded through a corporate grant (“subsidy”), sometimes referred to as a tax on the business units.[25] While it is rarely “blue sky” in public companies, it is still not yet specific enough for a business unit to see its immediate relevance to their profits.[26] Research is also far less internationalized than development, and only a few of the companies we have interviewed conduct basic or applied research (“big R”) outside their home country. Thus, although R&D expenditures for companies

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[25] For those companies that have central research laboratories, they varied in size from only 2% to 10% of a company’s R&D budget, with both extremes being computer companies.

[26] Japanese laboratories described 30 of their research funding as coming from business units. U.S. telecom firms appear to face extraordinary pressure from shareholders and chief executives to find business unit funding for nearly all of their research budgets. In some cases, they are funding this work

often make R&D appear very international, these expenditures are predominantly for development. In the few cases where research is done outside of the home country, it is often motivated by a desire to work more closely with overseas universities or experts in a field, but in many cases was simply the result of a previous merger.

Many companies emphasized the need for close cooperation and collaboration in their research groups, and one said a major obstacle for their research was time zone differences – in contrast to the stories of 24/7 efficiency (such as in global software programming).

There are a wide variety of motivations driving the internationalization of development, generally related to proximity to customers and markets. For example, for auto manufacturing, car models are developed to take advantage of local market knowledge, nearby suppliers, and regional manufacturing facilities. For pharmaceuticals, drugs have country-specific regulatory requirements, unique health care practices, and varying availability of clinical participants. For telecom and computers, different regions have different communications standards, needs for unique language interfaces, and varying receptivity to new devices.

Business Unit Organization of R&D

Nearly every firm we interviewed has recently undergone major changes in the organization of their business units and the structure of their R&D activities. In particular, nearly half the firms said that the structure of their divisions would have been radically different as little as two years ago. These changes were generally attributed to the rapid changes in high-technology markets, and often were a result of recent mergers. Many executives described the changes as movements toward globally integrated matrix management, where functions and business units are consolidated globally.

R&D was often not a fully consolidated function – for those firms that had separate research laboratories, the head of these labs typically reported directly to the CEO, while development was part of business units. In these cases, there is no individual responsible for both research and development.

Within research laboratories, there is substantial interaction with the business units. One computer manufacturer in Japan used the diagram shown in Figure 3. In this firm, research is handed off to business units as it becomes focused on specific products or processes, and the

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with technology licensing revenues.

laboratory stays involved (less so over time) as it moves toward marketability. In many cases, research personnel are even transferred temporarily to business units during this process. R&D on the right-hand side is funded by a corporate subsidy, and only covered by business units as it moves into development.

Internal transfer of technology is described as quite difficult, and some firms use elaborate information systems to ensure that their technologies and knowledge/experience are readily available to engineers in their manufacturing facilities globally. Such systems may allow firms to internalize knowledge spillovers and realize what economists call total factor productivity gains. In other firms, marketing functions are duplicated in the research unit to ensure that their technologies are not overlooked in the market. A couple of firms described their technology transfer model as requiring the transfer of personnel, with one firm describing resulting turnover rates of as much as 40% of R&D staff in one year from the laboratory to business units.

The Role of Outsourcing and Collaborations

There are a variety of models of innovation: some firms perform all of their R&D in-house, while others outsource much of their work to dedicated research firms; still others appear to do no R&D. Dedicated R&D firms can offer their clients cutting-edge technology as well as "spillovers" from their work for competitors. Even in the cases of those firms that do much of their R&D in-house, many utilize outside firms for project-specific tasks at cost-effective rates, from IT work to development of particular components (i.e. part prototypes for autos). Firms cite advantages of flexibility in making decisions about utilization of labor, efficient use of capital, and specialization in their areas of expertise.

Basic research appears to be moving increasing out of the business sector as a result of market pressures. Nearly all firms are heavily involved with university collaborations, and consider it a very important part of the R&D work. Moreover, many firms' international R&D investments are motivated by a desire to work closely with particular universities, and to transfer this knowledge to applied research and advanced development. However, the importance of work with universities is much greater than the expenditures that are involved. No firm devotes a large share of their R&D budget to these activities, despite their perceived importance.

Tapping of expertise is a major goal of the companies in their work with universities, and small-scale grants are adequate to facilitate this objective. Centers of excellence in particular fields are targeted, and many of the firms we have interviewed describe activities with the same handful of universities – MIT, Princeton, Oxford. In the case of several Japanese companies we interviewed, working with U.S. and E.U. universities was their primary motivation to do basic research overseas.

Choice of Location and Cost

As described previously, a variety of factors have affected the location choices of firms' R&D, including proximity to expertise, knowledge of local markets/customers, ties with suppliers or manufacturing facilities, and regulatory factors. In all of our interviews, cost itself was not considered to be a major factor, as it is often dominated by other considerations.[27] The potential return on innovation is considered to be much more important than the cost R&D inputs.

The Cost of R&D

Many firms felt that the cost of doing comparable "routine R&D" in Europe and Japan is somewhat more expensive (20-30%) than in the United States. A couple of companies noted that the U.K. may be slightly cheaper – 90%, and southern Europe (Italy) even more so – 70%. However, they felt that cost differences with Europe in general are not large enough to make much difference. And while many consider Japan to be significantly more expensive by standard measures, after accounting for quality, the differences are not very significant. However, those firms that had experience with China (and India) said that it is much lower in cost, even after quality is taken into account.

As shown below, while "routine R&D" was considered to be somewhat more expensive in E.U. countries than in the U.S., the cost of doing innovative work was significantly more costly. This example firm attributed the problems to a lack of entrepreneurial behavior ("outside the box thinking") outside the U.S. This implies that costs may need to be adjusted for their expected output to make them fully comparable.

A sample firm gave us the following estimated costs:

[27] Nevertheless, cost estimates are essential for accurate international comparisons of the amount of *real* effort involved in R&D.

	U.S.	China	Germany	Japan	Belgium	U.K.
“Routine R&D”	1.0	0.6	1.5	1.5	1.3	0.9
Labor only	1.0	0.4	1.5	1.8	1.5	0.8
For innovation	1.0	2.0	2.0	2.0	1.4	1.3

Measuring Cost

We have dealt with a number of key methodological issues in comparing different countries’ R&D surveys in Appendix A1 and A2 (researcher definitions, depreciation, etc.). However, there are several additional conceptual issues that came up during the interviews that do not relate directly to the surveys.

The first is that economic cost is rarely used by any of the firms in their decisions – only accounting cost is considered. So, the costs of purchased assets are typically considered very small in proportion to comparable rental costs based on to the purchased asset’s service life (and opportunity cost). This could distort decision-making by underestimating depreciation.

Second, the costs of clean rooms, chip fabrication plants, and proving grounds (for autos) are extraordinarily large, and significantly change the cost structure of R&D for related activities. Such large investments overwhelm other expenses and lead to path-dependent R&D investment. Moreover, many firms outsourced their most capital-intensive tasks (even leading to some variability in whether R is more labor intensive than D). How the firm treats these expenses (or related depreciation) can dramatically affect its measured R&D expenditure pattern.

Third, it takes time and structural reorganization to realize the effects of many new technologies. Thus the cost benefits of certain types of automation – such as screening for numerous molecules simultaneously or rapidly fabricating and testing prototypes of new products – may not be realized for some time after the initial investment.

Quality of Personnel

The important differences in the content of research and development play out directly in the composition of their respective scientists and engineers. Research work predominantly is done by Ph.D.s, while development is done by a combination of personnel with bachelor and masters degrees. Most executives characterized Japan as using fewer Ph.D.s than the U.S., and Europe as using more.

All firms claimed to pay highly competitive (market) wages to their scientists and engineers, with some U.S. firms saying that they paid equally qualified R&D employees a 10-15%* premium over comparably qualified employees in other business units. Expertise in a particular field was considered to be the most important distinguishing factor for personnel choices, and wages often varied considerably across fields.

Working hours were frequently mentioned when executives compared their international R&D work. Japanese employees were uniformly characterized as working significantly more hours than their U.S. counterparts, while Europeans work fewer hours than those in the U.S. However, no company appeared to be satisfied that they could accurately measure work differences in FTE-hour equivalents – thus we should be careful when interpreting R&D survey labor input.

Measuring R&D Output

Most firms stated that the output of their development work could be measured reliably using business unit evaluation: if the unit is satisfied with the result and continues funding, then the work should be considered successful. However, in earlier stages of R&D work, this approach becomes much more difficult, and it is often funded by corporate H.Q.[28] Other approaches such as spin-offs had been considered by many of the firms, but few had successful experience with these types of strategies.

Nearly every firm we spoke with described the challenge they face with attempting to measure and evaluate the output of their research work. They all faced pressure from senior management and shareholders to better justify their research expenditures and to apply a more rigorous system to its measurement.

Many of the companies described the use of a systematic stage-gate process for evaluating their development process. Several also described the consideration of real options methods to evaluate their research, yet only one pharmaceutical company said they have the system in place. This system regularly evaluates R&D activities from a retrospective and a prospective viewpoint.

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[28] One firm in the telecom industry utilized its licensing revenues to directly fund its basic research, in place of corporate "subsidies" due to shareholder pressure. On the other hand, most firms considered their licensing income to be unimportant and was simply a way to offset losses from "unsuccessful" technologies. Patenting more generally was considered important and usually rewarded generously; however, many technologies were not considered to be patentable.

A more common approach has been to develop a basket of metrics that reflect a broad range of research performance characteristics (sometimes called a balanced scorecard). One well-regarded company uses the following: achievement of goals (such as a new product), external recognition (papers/citations), scientific accomplishments (like a patent), and cooperation with business units (based on evaluations). These achievements are evaluated variously on a company-wide, group, project, and individual basis to ensure that research is on track and the correct incentives are in place.

7.2 Plans for the next year

There are a number of extensions and improvements that are planned for the analytic work and the interview process in the remainder of the project:

Interviews

- So far, we have completed interviews in the U.S., Japan, and Europe. (Some of these interviews have not yet been included in this report.) Additional interviews in each location to broaden our coverage will be necessary. We also plan to interview some firms in China, where we have been told the largest cost differences arise and solicit feedback from two global councils of R&D executives in September.
- Extend survey instruments to focus more precisely on the distinctions between Research and Development that we have observed. This will include more on the applied/basic research distinction.

Time and Country Coverage

- Convert the bilateral PPPs to multilateral (using the EKS method).
- Complete a manufacturing-wide R&D PPP comparison for our study countries in 1987.
- Make a rough manufacturing-wide R&D PPP estimate for China in 1995.

Detailed Industries

- Expand the R&D PPP work on broad manufacturing industries to cover the four detailed high-tech industries. This work will rely more heavily on the firm interviews to calculate R&D PPPs.[29]
- For the high-tech industry output we plan to obtain or calculate quality-adjusted output PPPs. Estimates that use hedonic methods will be used where possible to account for the large quality differences that exist across countries.[30]

Sensitivity Analysis and Quality Adjustment

- Product composition and mix adjustments will be explored. Related broad and detailed industries will be compared in order to assess the sensitivity of results to the product mix of industry categories, as well as aggregation effects.
- The applicability of the unit value approach will be evaluated in those industries where R&D generates many new products. New product information from the innovation surveys is available for the Netherlands, Germany, and the U.K.
- If we identify additional information on the U.S. share of support labor expenditure, we will make adjustments, given the sensitivity of R&D PPP estimates to different assumptions.
- Adjust R&D wage rates to reflect average differences in working hours in different countries.

Exploring Implications

- More fully describe the substantive distinctions between Research and Development in the context of internationalization. A literature review on this topic is currently in progress. In addition, determine the full range of statistics available (such as from national R&D surveys) for making distinctions between Research and Development internationally.
- Explore the economic implications of company allocation of Research centrally and Development across countries. Address theoretical questions about where the resulting

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[29] Due to the large variability in cost structures and available detail that we have found among firms in the same industries, the information will probably be used in a somewhat informal way. For example, we have already used the interview information to select detailed price parities and basic headings for use in the broad manufacturing comparisons. Our tests so far suggest that the largest differences will arise from the selection of PPPs rather than the weights, so our work will focus on these distinctions.

[30] Some progress has been made in complementary studies of the auto, computer, and pharmaceutical sectors, but telecom has only been examined inter-temporally.

productivity gains should be observed. If feasible, examine these issues econometrically using the U.S. NSF R&D Survey microdata, which separates research from development and domestic from international R&D.

- Consider the business implications of our results on the internationalization of R&D and communicate them to a business audience. For example, what does the convergence of the price of international R&D mean for business?

Measurement Issues and Indicator Products

- Communicate the technical findings through research paper(s) for the academic community.
- Design a workshop at the culmination of this project to broadly examine the applications of our results for statisticians and economists.
- Solicit and receive feedback from National Science Agencies, the OECD, and fellow researchers. Consider the full range of applications of the R&D and output PPPs for the purposes of S&T indicator development. For example, determine if our indicators are revealing about institutional motivations for Development, such as with health, safety and environmental regulations (as well as geographical ties with manufacturing and marketing). An estimate of the impact of these effects may be feasible by examining allocations of R&D compared with their cost since cost itself is not considered a major factor in interview responses.[31]

[31] Another example comes from work by the OECD on indicators of competitiveness using export UVRs as measures product quality (Aiginger, 1997); this work may have relevance for our analysis of R&D and industry output UVRs because it may allow us to separate out price/quality issues from institutional ones.

Appendix A1, Definition of high-tech industries

For this project we selected four industries, that are among the most R&D intensive (and are thus defined as high-tech). These industries are pharmaceuticals, computers, telecommunication equipment and automobiles. Table A1-1 shows how the ideal industry classification looks like according to the national classification systems. The table shows the definition according to ISIC rev. 3 (International Standard Industrial Classification), NACE (fran. Nomenclature generale des Activites economiques dans la Communaute Europeenne) Rev. 1, U.S. SIC (Standard Industrial Classification) 1987, NAICS (North American Industrial Classification System) and JSIC (Japan Standard Industrial Classification). This table presents the ideal internationally comparable set of industries, but in practice we sometimes have to deviate because data is not available at such a detailed level. This is the case in (for example) the computer industry where in many countries, data is only available for NACE industry 30 as a whole, which then includes office machinery like typewriters as well. However, the table as presented here defines the benchmark.

Table A1-1, Classification of high-tech industries in the U.S., Europe and

Pharmaceuticals		
ISIC	2423	Manufacture of pharmaceuticals, medicinal chemicals and botanical products
NACE	24.40	Manufacture of pharmaceuticals, medicinal chemicals and botanical products
NAICS	3254	Pharmaceutical and Medicine Manufacturing
USSIC	2834	Pharmaceutical preparations
JSIC	206	Manufacture of drugs and medicines
Computers		
ISIC	3002	Manufacture of computers and other information processing equipment
NACE	30.02	Manufacture of computers and other information processing equipment
NAICS	3341	Computer and Peripheral Equipment Manufacturing
USSIC	357(ex3579)	Computers and computer equipment
JSIC	305	Electronic data processing machines, digital and analog computer equipment and accessories
Telecommunications Equipment		
ISIC	3220	Manufacture of television and radio transmitters and apparatus for line telephony and line telgraphy
NACE	32.20	Manufacture of television and radio transmitters and apparatus for line telephony and line telgraphy
NAICS	3342	Communications Equipment Manufacturing[a)]
USSIC	366	Communication equipment
JSIC	304	Manufacture of communication equipment and related products
Motor Vehicles[b)]		
ISIC	3410	Manufacture of motor vehicles
NACE	34.10	Manufacture of motor vehicles
NAICS	3361	Motor Vehicle Manufacturing
USSIC	3711	Motor vehihicles and car bodies
JSIC	311	Manufacture of motor vehicles, parts and accessories

Notes:

a) This excludes some repair services, which are included in the ISIC and NACE definitions, but are probably relatively small

b) Ideally, we would like to exclude trucks, buses and motor vehicle engines.
For the U.S., this can be easily done by taking industry 33611, but it may not be possible for Europe and Japan.
The fact that Europe and Japan also include some repair services is probably less important.

Appendix A2, Comparison of firm and industry R&D expenditure shares

For the four high-tech industries we define, we collect data on the cost structure of the firms we interview. So far, we have nine such cost structures for firms operating in the U.S. based on seven interviews (for two companies we have separate information on both research and development costs). For Japan we have seven cost structures, based on six companies. These data allow us to compare the cost structures of the firm to the corresponding cost structure based on the national R&D surveys for those industries.

The first thing that becomes clear is that the cost structure differs widely by company. For example, in the U.S., the labor share varies between 25% and 75%. In Japan this range is 31% to 77%. To some extent, this may be due to the fact that we have figures for Research and Development separately (for most firms we have only research figures). On average, Research has a higher labor share of 60% compared with development, which is only 43%. In interpreting these numbers, it is good to also take note of the range of observations we currently have. For Research, we have 14 observations divided equally by the U.S. and Japan, while for Development there are only four observations (3 U.S., 1 Japan). Nevertheless, the finding of higher labor share in research holds up in both Japan and the U.S. Also, based on our interviews, the result is plausible since much of Development involves large equipment like prototypes in the car industry or semiconductor 'fabs' in other high-tech firms.

Given this observation, we would expect that Development would similarly show a higher share of equipment than the overall industry. However, due to restrictions on the capitalization of R&D assets, we first look to see if Development has a higher share of materials inputs. Given the data we have so far, we cannot establish that the Development labs have higher materials shares. One observation confirms the conjecture, two deny it, while for the fourth we do not have separate data on material spending. We do tend to see that in Research departments, the materials share is lower than for the industry as a whole (based on the R&D surveys). This is the case for 7 of the 11 observations. The average material share in research is also lower than in development.

One other way to corroborate this would be to look at the cost shares for foreign affiliates. Our interviews with these types of firms suggest that they usually do not have or buy the same type of equipment as is available in the home country. The alternative for these affiliates is sometimes to let headquarters do that part of the Development. This course of action would lead to a higher labor cost share. We do find some evidence of this, although it is not the case for all foreign affiliates that they have a higher labor cost share than other firms do.

We also ask the companies to report the cost share of capital depreciation. This should be comparable to the question in the RD-1 survey on R&D depreciation. However, the U.S. firms invariably report a much higher figure for capital depreciation than the industry average for "R&D Depreciation". While R&D depreciation from the RD-1 survey varies between 0.4% and 2.9%, capital depreciation from the U.S. firm data varies between 1.2% and 9.9%, with most observations near the high side of this range. We might even be underestimating depreciation for R&D as a whole because we are mainly looking at the costs for the research departments. As mentioned above, the development side is usually more equipment intensive although for capital depreciation, the findings are not unambiguous either. In general, however, the NSF R&D Survey responses are generally too low, which might indicate that firms are misinterpreting the question as asking for things like own-account software depreciation.

What we can observe is that the figures from individual firms are generally very different from the survey average. In the U.S., firm responses indicate that both the labor and the capital share are higher than in the surveys, with either the materials or the other current expenditure share being lower. We noted before that the labor share in the U.S. varies between 25% and 75% for the firm data. The survey data vary between 32.6% and 53.3%. In the U.S., 8 of the 10 labor shares are larger than the surveys indicate. In Japan the firm data indicate a range for the labor share between 31% to 77%, while this range is 37.3% to 44.6% based on the survey. Moreover, 6 out of 8 observations are larger than the corresponding survey figure. Since our data are primarily for Research laboratories, these observations confirm our prior that Research departments is more labor-intensive than R&D in general. In the case of the U.S., the higher capital share would argue against such a conclusion, but we argued above that this information may be misreported in the RD-1 Survey.

Appendix A3, Representativeness of interviewed firms

In order to evaluate the representativeness of the firms we interviewed, we compared each company's R&D intensity to that of the other companies in the same industry, using the weighted average and median R&D intensity based on *Compustat* and the overall R&D intensity based on national R&D surveys ("target intensities"). The weighted average Compustat intensities should be relatively close to the survey intensities, but they do not match completely because of differences in coverage, scope, and definition. First, Compustat only covers publicly traded companies while the R&D surveys also cover private firms. Second, Compustat includes R&D by foreign affiliates in the data for the home country, while the R&D surveys only cover R&D performed within the country. Third, the NSF definition of R&D differs from that of the SEC in a number of respects. For example, the Compustat data do not include spending on social sciences research. For more information on these differences and their impact see Hall and Long (1999) and NSF (1999).

All of the selected companies we interviewed perform a large amount of R&D, ranging from 3.5% to 21% of sales. The R&D intensity of the companies we interviewed is generally in a similar range to the target industry-wide intensities, although the spread between these target intensities can be quite large. For example, in the telecom industry, (publicly traded) U.S. firms in Compustat show nearly twice as large of an R&D intensity compared with the NSF R&D Survey. Since our selected firms are primarily publicly traded corporations, in the telecom industry, we appear to be sampling from the higher end of the R&D intensity distribution. On the other hand, in the computer industry, we may be sampling from the lower half of the distribution. Still, the firms are rarely outside the range of the three target industry-wide intensities. Especially in the pharmaceutical and motor vehicle industries, our selected firms appear to have R&D intensity very close to the target 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 and in some cases overwhelming. These results suggest that conclusions we draw based on the firm interviews and cost structures directly reflect a sizable part of each industry and should also be broadly representative of the firms in each industry.

Appendix A4, A note on the product matches for Output PPPs

Table A4-1 gives an overview of the number of matches in each industry:

Table A4-1, Number of product matches for the manufacturing output PPPs

	France	Germany	Japan	Netherlands	U.K.
Food and kindred products	103	132	23	75	73
Textiles, wearing and leather products	37	76	45	30	63
Wood, paper products, printing & publishing	25	32	12	9	18
Chemicals & allied products	29	59	38	19	32
Petroleum & coal products	0	0	9	0	0
Rubber and plastic products	3	4	4	3	2
Non-metallic mineral products	14	23	11	3	15
Basic metal products	26	43	37	7	34
Fabricated metal products	2	11	9	5	2
Machinery & equipment	13	39	22	4	23
Transport equipment	1	6	7	2	2
Electrical machinery and instruments	14	55	14	4	44
Furniture and miscellaneous manufacturing	1	36	0	11	12
Total manufacturing	268	516	231	172	320

Differences between countries are large. In Germany, 516 different products could be matched to the U.S., while in the Netherlands this could be done for only 172 products. This is not only the result of more detailed matches, but also of simply better coverage of the industries. The U.S. coverage ratio (defined as matched output over industry output) in the German comparison was considerably higher than in the Dutch comparison. Of total industry output in the U.S., 28.3% was covered in the German comparison but only 13.6% in the Dutch case. The number of matches and the coverage ratios are mainly of interest as an indicator of the reliability of the UVRs. To assess the stability of a UVR, we can calculate a coefficient of variation. This only gives information on the variation between the matches that are able to be made. For the industry output that is not covered, we have to rely on the more qualitative indicators of number of matches and coverage ratios. Overall, the comparison cover between 15 and 20% of manufacturing output, varying between only a few percent in the case of industries like electrical machinery to more than 50% in the case of the food industry. See other studies like van Ark and Timmer (2001) or Inklaar, Timmer and van Ark (2002) for a more detailed description and discussion of the reliability of these ICOP PPPs.

Especially for the high-tech industries, the development of reliable output PPPs is problematic. Some products, like routers, are not produced in some countries, making matching impossible. Furthermore, if similar products are produced in both countries under consideration, these products may differ on a number of characteristics. As van Mulligen (2002) shows, cars produced in the U.S. are usually larger than their European or Japanese counterparts. So to construct a good PPP, this needs to be taken into account, either through detailed matching or through hedonic methods. Van Mulligen (2002) presents hedonic PPPs for all our countries, except the Netherlands, while Moch and Triplett (2001) a hedonic PPP for computers for France-Germany. Danzon and Chao (2000) present PPPs for pharmaceuticals based on very detailed matching for all countries except the Netherlands.