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10

International Comparisons of R&D Expenditure
Does an R&D PPP Make a Difference?

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

10.1 Introduction

Concerns with science and technology (S&T) capabilities are widespread in the United States as well as in other developed countries. This is understandable in light of the importance of knowledge and technology in generating long-run growth of productivity, per capita income, and employment. Trends and levels of research and development (R&D) spending and, in particular, ratios of R&D expenditure to gross domestic product (GDP) or national income are often used as a measure of innovativeness as they capture the resources devoted to achieving future technological change.[1] In Europe, for example, governments at the Barcelona European Council noted

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This research is made possible by grant SRS/SES 00-99594 from the National Science Foundation (McGuckin, van Ark, et al. 2004) and was carried out while the authors were all residing at The Conference Board. Related work was presented at seminars of the National Academy of the Sciences in Washington, D.C.; the OECD Science, Technology, and Industry Directorate in Paris; the NBER Conference on Research in Income and Wealth Summer Institute in Cambridge, MA; The Conference Board's International Innovation Council in Cambridge, U.K.; and the meeting of the Canberra II Group on the Measurement of Non-Financial Assets in Voorburg, The Netherlands. We received particularly useful comments from Andrew Wyckoff and Dominique Guellec (OECD), Jeffrey Bernstein (Carleton University and NBER), and Ernst Berndt (MIT and NBER). We are deeply saddened that our coauthor Robert H. McGuckin passed away in March 2006. His contribution to the economics profession will live on through his extensive published work.

1. Policy discussions must also consider the productivity and composition of these efforts, which are likely to differ across countries (and industries) as well as the magnitudes of the

that European R&D expenditures are well below those of the United States and set a target to dramatically increase R&D spending from 1.9 percent of GDP to 3.0 percent by 2010 (European Commission 2002).

Whereas nominal R&D intensity provides a measure of the burden (in monetary terms) on society of R&D activities, it is less informative about the real resources devoted to R&D because it does not take into account differences in relative prices of R&D inputs across countries. For this purpose, R&D-specific purchasing power parities (PPPs) are needed, which measure how much needs to be spent in a country to acquire one U.S. dollar's worth of R&D inputs.[2] Hence R&D expenditures that are converted at R&D PPPs will give a better measure of the differences in actual resources devoted to R&D between countries. In this sense, PPPs are comparable to price deflators that adjust nominal values for price changes to arrive at real, or volume, measures.

When making international comparisons of R&D, PPPs should reflect differences in relative prices. Because R&D output prices cannot be directly measured, we need to focus on the prices of R&D inputs. Most studies and statistics use aggregate proxies, such as the PPP for GDP, but these will generally not suffice. While GDP PPPs reflect relative prices of primary inputs—labor and capital—each input's representation in GDP does not reflect its importance to R&D, and they are not specific to R&D. Moreover, GDP is based on the concept of final goods and services, rather than the intermediate goods and services that make up a large part of R&D expenditure. Finally, use of GDP PPPs does not capture differences in the industrial composition of R&D across countries. While use of industry-level nominal R&D expenditure can partially address the composition issue, remaining distortions in prices can be a serious problem.

Taking the latter point a step further, when focusing on real R&D intensities by industry, not only the numerator—R&D expenditure—needs to be converted using a specific R&D PPP, but the denominator—industry output—also requires an industry-specific output PPP. The use of a GDP PPP to adjust for relative price levels in manufacturing would be equally inappropriate. Recent experience with industry-level PPPs from the International Comparisons of Output and Productivity (ICOP) project suggests

spillovers generated. In examining these issues, it is important to develop R&D capital-stock measures rather than focus only on current expenditures. While these issues are not dealt with in this paper, PPPs and price deflators are basic building blocks for this type of analysis.

2. As rates of equivalence for comparable goods in local currency prices, purchasing power parities (PPPs) have the same units as exchange rates. If PPPs and exchange rates are the same, then there is no difference in relative prices or cost across countries. However, there are many reasons why exchange rates are not good substitutes for PPPs. Of particular relevance to R&D, there is no necessary reason why the relative prices of goods that are not traded internationally should conform to exchange rate values. Exchange rates are also vulnerable to a number of distortions, for example, currency speculation; political events, such as wars and boycotts; and official currency interventions, that have little or nothing to do with the differences in relative R&D prices across economies (National Science Foundation 2002).

that substantial differences exist between manufacturing output PPPs and GDP PPPs, even for economies at similar levels of development (van Ark 1993; van Ark and Timmer 2001). Therefore PPP adjustments—taking account of differences in the structure of relative prices of R&D inputs and output across economies and industries—may be worth the considerable effort required for their measurement.[3]

A search of the literature finds relatively little empirical work on R&D price indexes, particularly across countries. In fact, the latest R&D PPP estimates we could find were done in the early 1990s for the year 1985. Typically, the issue is either ignored because detailed price data are not available or a GDP PPP is used in cost comparisons. For comparisons of R&D intensity, nominal values are usually employed. To compare R&D expenditure over time, a GDP deflator is most commonly used. The lack of good measures in the area of R&D price indexes has not gone unrecognized. Zvi Griliches lamented the lack of good information on the "price" of R&D in his remarks twenty years ago, on the occasion of the National Bureau of Economic Research (NBER) Conference on R&D, Patents, and Productivity (Griliches 1984). Griliches further emphasized the importance of having reliable information on R&D and its price to compare expenditures and intensities in his presidential address to the American Economic Association (Griliches 1994).

This paper brings together a wide range of statistical data to develop relative R&D prices for nineteen manufacturing industries in six Organization for Economic Cooperation and Development (OECD) countries—France, Germany, Japan, the Netherlands, the United Kingdom, and the United States—with the United States as the base country. This exercise is undertaken for two benchmark years, 1997 and 1987, chosen because these are years with information from the U.S. Economic Census, benchmark international PPP studies on industry output, and comprehensive R&D surveys from each of the countries. Industrial census data and collections of international prices are used to compare prices of intermediate goods. Data from national R&D surveys of business enterprises are used to develop R&D-specific prices and quantities. Interpretation of the data was also guided by information collected in over thirty-five interviews of R&D executives at international affiliates of multinational companies in four of the most R&D-intensive industries: pharmaceuticals, computers, telecommunications equipment, and motor vehicles. The interviews were invaluable in understanding issues of comparability in different countries' data, due to differences in reporting practices, tax regulations, and interpreta-

3. The Frascati Manual (OECD 1994, 12) states that "[R&D intensity] indicators are fairly accurate but can be biased if there are major differences in the economic structure of the countries being compared." Arguably, because R&D is not a tradable commodity and one of its major components is labor, whose price exhibits great differences across countries, such differences are probable.

tions of R&D definitions, among other issues. Moreover, we gleaned important qualitative information that was useful in interpreting the implications of the results.[4]

In the sections that follow, we first review previous research on R&D PPPs and its limitations. Next we describe our estimates of manufacturing R&D PPPs for 1997 and 1987. These PPPs are used to compare international R&D cost levels and intensity. We then assess differences with current practices. We find that our preferred R&D PPP measure can be simplified without a large impact on the results. This alternative resembles the Griliches-Jaffe R&D deflator and is far easier to construct than our most preferred measure. Both measures differ substantially from the GDP PPP.

10.2 Previous Research on R&D PPPs

This study is not the first to address the problem of estimating PPPs for R&D. Nevertheless, there has been relatively little effort to create R&D PPPs, particularly compared to the volume of work carried out by official statistical agencies in the price index area. While there are many reasons for this state of affairs, an important factor is that R&D expenditures are not yet incorporated into the System of National Accounts.[5]

A key issue in estimating R&D PPPs is that the output of R&D cannot be easily defined. If R&D were a typical economic activity, like the production of steel or cotton, then standard measurement of quantities and prices could be applied. However, the results of R&D often are ideas and other intangibles that are typically in the hard-to-measure area.[6] Moreover, R&D services are often transferred within the firm rather than traded on markets so prices are hard to measure. As a result, measurement of R&D prices has generally focused on constructing input price indexes, which can be used to assess differences in costs. This approach has characterized all the major studies from the 1960s onward.[7] Given the difficulties

4. The interviews are not described in detail in this paper. More information can be found in McGuckin et al. (2004a,b). Large multinational R&D performers in four high-tech industries in the United States, Japan, and Europe were selected for face-to-face interviews. Even with the small sample, coverage of many countries' industries is substantial. Interviews involved structured discussions about firms' R&D organization, composition, and reporting practices. A detailed financial questionnaire on R&D costs items and expenditures was also completed by about one-third of the interviewed firms.

5. See Fraumeni and Okubo (2005) for recent work on developing R&D measures in the framework of the U.S. National Income and Product Accounts.

6. In related work, we have found that although research is for the most part intangible, development is quite different and has physical dimensions that should be relatively easier to measure (McGuckin, Inklaar, et al. 2004).

7. One quite different approach has been applied to pharmaceuticals, where the total cost of an innovation is priced out over its development cycle, including the cost of failures (DiMasi, Hansen, and Grawbowski 2003). While this approach has great appeal when assessing the cost of a specific innovation like a drug, it is harder to apply in other industries and says little about the relative cost of performing R&D in different countries.

in measuring output even for relatively well-defined high-technology products, such as Information Technology (IT) capital, some caution should be used when interpreting price indexes for R&D.

10.2.1 Overview of Earlier Studies

In most of the literature, the relative cost of R&D across countries is estimated based on prices for a basket of "standard" R&D inputs at the economywide level.[8] Freeman and Young (1965) performed the first of these studies. Their work was undertaken for the year 1962, before the first edition of the Frascati Manual (OECD 1963), and they did not benefit from the more comparable survey instruments in use today. Nevertheless, they use expenditure categories similar to those we apply in this study. Freeman and Young estimate a PPP for R&D by breaking up total R&D expenditure into labor costs, materials, other current and capital expenditures. For labor costs they calculate the wage cost per worker in R&D and assume this is also appropriate for other current expenditure. For materials and capital expenditures, they assume the exchange rate is the appropriate price.

Brunner (1967) compares the cost of research projects subcontracted by the U.S. Department of Defense across a number of European countries. For these projects, subcontractors supply budget sheets, which contain data on total costs, including wages, benefits, support, and overhead costs. The cross-country comparability issues are likely to be smaller than in the Freeman and Young study as the Department of Defense imposes similar budget standards on all subcontractors. However, the estimate includes a very specific subset of R&D, and it is unclear if the budgets include all R&D costs (e.g., capital expenditures).

The work by MacDonald (1973) extends the previous two studies to sixteen OECD countries by calculating R&D PPPs relative to the United Kingdom.[9] He distinguishes between labor cost, other current cost, and capital expenditure. For the countries included in the Brunner (1967) study, MacDonald 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). His estimate of a capital PPP is based on relative prices from trade statistics, weighted using the aggregate expenditure on these products. For other current expenditure, he assumes the exchange rate is applicable. Based on these figures, he finds

8. The Conference Board (1976) and Mansfield (1988) directly queried firms about the relative cost of selected R&D inputs, but this approach is difficult to generalize to multiple industries and countries.

9. In table 10.1, we convert these to cost levels relative to the United States to facilitate comparability. This is appropriate as all PPPs are aggregated from individual cost category PPPs using U.K. weights, in effect creating a Laspeyres-type index. Although the Laspeyres index has its weaknesses, it is transitive.

Table 10.1 Previous studies of R&D PPPs—R&D price levels (cost relative to the United States)

Country	Freeman & Young (1962)	Brunner[a] (1961–62)	MacDonald[b] (1963–64)	OECD (1970)	Kiba et al. (1985)
France	66.7	42.4	60.0	73.3	76.8
Germany	58.8	28.7	60.0	70.6	85.4
Japan			35.3	57.1	81.3
The Netherlands	52.6		66.7	68.1	
United Kingdom	55.6	34.0	60.0	58.8	68.0
United States	100.0	100.0	100.0	100.0	100.0

Sources: Freeman and Young (1965), Brunner (1967), MacDonald (1973), OECD (1979), and Kiba, Sakuma, and Kikuchi (1994).

Notes: R&D price levels are defined as R&D purchasing power parity (PPP) divided by the exchange rate of the country's currency relative to the U.S. dollar. These levels represent costs relative to the United States.

[a]Refers to research costs only.

[b]Price levels are converted to use the United States as base country (original study used the United Kingdom as base country).

that R&D in the United States is around 40 percent more expensive and Japan 70 percent cheaper than in the United Kingdom (see table 10.1).

In 1979 the OECD published a study, presenting calculations for R&D deflators for the 1966 to 1976 period and an R&D PPP for 1970 (OECD 1979). Four cost categories are distinguished in the study: labor, other current costs, land and buildings, and instruments and equipment. The labor PPP is calculated as the average labor cost per R&D worker. A PPP for other current expenditure is proxied as the relative price of current government expenditure other than salaries from International Comparisons Project (ICP) studies. The two capital categories are also ICP-based: for land and buildings the PPP for nonresidential/commercial buildings is used, while for instruments and equipment, the PPP for electrical machinery items is used.

The most recent study is by Kiba, Sakuma, and Kikuchi (1994). The countries they cover are France, Germany, Japan, and South Korea, with the United States as the base country. Their breakdown of cost categories is more refined than in previous studies: they distinguish materials spending from other current expenditure, and they break down capital expenditure into machinery and equipment, land and buildings, and other assets. Because such a detailed breakdown was not available for all countries, estimates were made using data from countries where these distinctions could be made.

Kiba, Sakuma, and Kikuchi's (1994) basic approach is to select price parities from GDP final expenditures (ICP studies) to proxy each of the R&D input cost categories. They select their price parities based on the composition of items in the R&D industry of Japan's input-output use table. In cases where they cannot identify relevant input price parity headings from ICP, they use the exchange rate as the relative price. This same selection of prices is used for all countries. Their match between R&D categories and price parities is very rough and is based on only the Japanese structure of R&D inputs.

If the input-output tables were sufficiently comparable across countries, use of the input structure for the R&D industry could be very useful. However, our research indicates that the data for the R&D industry are not comparable. The problem is that the inputs allocated to the R&D industry depend on the institutional structure of the country and the related issue of which facilities are designated as R&D labs by data collectors. German R&D firms, for example, obtain a significant share of their intermediate inputs from the education sector, while in other countries, this share is nonexistent. In the United States, only stand-alone laboratories are included in the R&D industry and their inputs are very different from integrated facilities (McGuckin, Inklaar, et al. 2004).

10.2.2 Drawing Lessons

The methodologies used in these studies for calculating R&D PPPs contain several common features. As the OECD (1979) notes, an ideal approach would be to calculate the labor cost per employment occupational category (scientist, technician, or support), but limitations on the disaggregation of labor expenditure prevent this method from being implemented broadly. While Kiba, Sakuma, and Kikuchi (1994) use ICP government and educational labor PPPs as a proxy for an R&D labor PPP, this is likely to be a less-appropriate measure of the average labor cost per R&D worker. The latter method is commonly employed in studies on an economy-wide basis; we adopt the same approach at the industry level for this study.

Calculating a PPP for the other current expenditure category is a problem because it is difficult to determine exactly what inputs are in this category. In general, there are two major groups, purchased goods and purchased services. The first would include material costs (raw, nondurable goods) but, depending on statutory tax depreciation provisions, also machinery and instruments. The second, frequently referred to as overhead costs, can include anything from building rent to the purchase of scientific journals.

The procedure used by MacDonald (1973) that assigns the market 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. The OECD (1979) and Kiba, Sakuma, and Kikuchi (1994) take a more promising approach by using product-specific ICP expenditure PPPs to come up with a PPP for this cost category. A further point to note is that the price consumers pay for final consumption goods or firms for investment goods may not be relevant for intermediate input purchases by R&D labs.

MacDonald (1973); the OECD (1979); and Kiba, Sakuma, and Kikuchi (1994) develop capital PPPs using import and export prices. Unfortunately, these prices may not reflect prices paid for similar goods by R&D laboratories. It is probably more appropriate to select one or more PPPs for both land and buildings and instrument and equipment, as is done by the OECD (1979) and Kiba, Sakuma, and Kikuchi (1994) using ICP expenditure PPPs.

Finally, the aggregation used in most of these studies could be improved. The earlier studies use a weighted average of the category PPPs to calculate their economywide R&D PPPs. While the MacDonald, OECD, and Kiba et al. studies use a Laspeyres-type aggregation, for many countries they do not have complete expenditure weights. None of the studies calculates a Fisher-type index or some type of multilateral index, which are the preferred methods in PPP studies (Kravis, Heston, and Summers 1982; van Ark and Timmer 2001).

Despite the various shortcomings of each study, the studies provide a similar bottom line. Table 10.1 shows that the relative price of R&D of other countries compared to the United States had a strong upward trend between 1962 and 1985.[10] The table focuses on those countries that are included in this study. While R&D was initially less expensive outside the United States in every country, the gap narrowed substantially in the twenty years covered by these studies. For example, between 1962 and 1985, the relative cost level of R&D in Germany rose from around 60 percent of the United States in the early 1960s to 85 percent in 1985. These increases partly reflect the large changes in the exchange rates over these years, but changes in real cost play a role as well.

10.3 R&D PPP Estimation in Manufacturing

This work is motivated by concerns about the appropriateness of the current practice of using GDP PPPs for R&D expenditure and international R&D intensity comparisons based on nominal expenditures and output. Limitations on the availability and comparability of international data are the biggest obstacle to more systematic development of R&D-specific PPPs. While not all problems associated with calculating R&D PPPs can be resolved, there have been a number of improvements in data in recent years, and there are a number of areas for potential improvements. For example, work coordinated by the University of Groningen's ICOP group has created

10. Some studies originally used a different base country, but all have been recast to use the United States as the base country to facilitate the comparison.

databases of industry-level PPPs, supplementing the more widely available expenditure PPPs from the ICP programs of the United Nations, the World Bank, the OECD, and Eurostat (see Kravis, Heston, and Summers 1982; van Ark 1993; and van Ark and Timmer 2001).

In addition, the comparability of R&D data has improved, in part through the efforts of national statistical agencies guided by the OECD's Frascati Manual (OECD 1963, 1981, 1994, 2002). Nonetheless, it is far from clear whether companies in different countries report R&D costs in a similar way. For example, in one country companies may include purchases of new computers under current expenditure, while in others it may be reported as a capital expenditure.[11] This is one reason for the use of the firm interviews in our work. Still, the problems with comparability should not be overdrawn. The studies surveyed in table 10.1 demonstrate that similar results are found despite large differences in data availability and methodology.

10.3.1 Methodology and Procedures

We develop estimates of industry-specific R&D PPPs by aggregating individual price parities for major categories of R&D expenditures with expenditure share weights derived from national surveys. On this basis, we obtain R&D PPPs for nineteen manufacturing industries that are then aggregated to the total manufacturing level. The principal results of these calculations are two measures that we later use in assessing the cross-country differences. The first is an R&D PPP that measures the price of an R&D unit in a particular country relative to the price in the United States, the base country. This measure is in units of local currency per U.S. dollar and can be used to "deflate" R&D expenditures in the spatial dimension. Second, by dividing the R&D PPP by the dollar exchange rate, we obtain the relative cost (price level) of an R&D unit of input compared with the base country.

The R&D PPP for each individual industry is estimated from an aggregation of relative R&D input prices (price parities or just PPPs) using corresponding R&D expenditure shares as weights. For each industry and country pair, cost weights of the base country *u*—the United States—are used to create a Laspeyres PPP,

$$\text{PPP}_L^{x,u} = \sum_i w_i^u \text{PPP}_i. \tag{1}$$

Equation (1) is simply a share-weighted average of the individual PPPs for four input categories, labor, materials, other current costs, and capital expenditure, indexed by *i*. Weights are based on the share of each category's expenditure in R&D (of the base country in U.S. dollars):

11. See McGuckin, Inklaar, et al. (2004) for more discussion of comparability problems.

(2) $$w_i^u = \frac{C_i^u}{\sum_i C_i^u},$$

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

(3) $$\text{PPP}_P^{x,u} = \sum_i w_i^x \text{PPP}_i$$

and

(4) $$w_i^x = \frac{(C_i^x / \text{PPP}_i)}{\sum_i (C_i^x / \text{PPP}_i)},$$

where w_i^x is the expenditure share of input category i in the comparison country (x) converted into U.S. dollars using the corresponding PPP. Taking a geometric average of equations (1) and (3) yields a Fisher PPP, the measure of the price of R&D in local currency units of country x per U.S. dollar.

Dividing these PPPs by the exchange rate provides a unit-free index measure of relative R&D costs compared to the United States, which is the base country in all the calculations. Thus, all of the comparisons are made on a bilateral basis.[12] We now turn to the details of the PPP calculations and their sensitivity to various assumptions and data.[13]

10.3.2 R&D Input Prices and Weights

Computation of R&D PPPs requires both prices and weights for each category of R&D input. We identify four main categories of R&D input: labor, materials, other current costs (overhead), and capital. Weights for each category are based on each input's representation in R&D expenditure. This industry-level expenditure information comes from summary data compiled by the OECD based on national R&D surveys in each country. We also use industry-specific R&D input prices for labor and materials and economywide prices for other current costs and capital. The labor PPPs rely most heavily on comparisons of wages for R&D personnel, derived primarily from the national R&D surveys. We develop independent estimates for the price of material inputs, other current expenditures, and

12. These bilateral PPPs for each country pair differ from multilateral PPPs as used in the expenditure PPP programs of ICP (see, for example, Kravis, Heston, and Summers 1982). In practice this could mean that some of our pairwise R&D PPP estimates are not transitive. However, given that we only cover six countries in this study with relatively similar cost shares, the gains from using multilateral indices were found to be modest.

13. Note that the industry-level PPPs are aggregated across industries using a Fisher index in order to obtain manufacturing-wide PPPs. This procedure takes account of differences across countries in industry weights.

Table 10.2 R&D PPP input categories and price measures

R&D input category	Input prices: Measure	Input prices: Source	Industry specific?	Average weight (%)
1. Labor compensation	Average wages for R&D personnel	NSF/OECD	Yes	49
2. Materials and supplies	Price of industry's output adj. for margins	ICOP	Yes	18
3. Other current costs	Prices of overhead goods and services	ICOP/ICP	No	24
4. Capital expenditure	Prices of plant and equipment	ICOP/ICP	No	9
Total R&D[a]			Yes	100

Sources: National Science Foundation (2002); OECD (2002b, 2003); ICOP 1997 (O'Mahony and van Ark [2003] and Inklaar, Wu, and van Ark [2003]); ICOP 1987 (van Ark [1993]).

Notes: ICOP = International Comparisons of Output and Productivity Project, University of Groningen; NSF = National Science Foundation; ICP = International Comparisons Project (United Nations, World Bank, Eurostat, OECD).

[a]Aggregation of R&D input category prices to total R&D uses R&D expenditure weights from national R&D surveys.

capital using the industry-of-origin PPPs from the University of Groningen's ICOP program, which are based on item-level matches derived from production census and industrial survey data in the United States, European Union, and Japan. We supplement this information with PPPs derived from ICP studies using the expenditure approach (OECD 2002b) after making appropriate adjustments to "peel off" estimated margins for transportation and distribution (see Jorgenson and Kuroda 1992; van Ark and Timmer 2001). The firm interviews, as described in McGuckin, van Ark, et al. (2004), are used to inform the necessary assumptions that are made regarding the structure of R&D expenditure and about how to use the data in a way that approaches a constant quality of input basis.

Table 10.2 provides an overview of measures and sources used for the R&D input prices for the construction of the R&D PPP measure. In the following, we discuss our input price measures and weights in some detail and examine possible variants to our preferred measure. Additional details on the estimates are available in an online appendix (McGuckin, van Ark, et al. 2004).

Labor

Labor is the largest component of R&D cost, averaging about half of total expenditures. Average R&D compensation per R&D employee, based on national R&D survey information, measures the price of R&D labor for R&D performed within business enterprises (intramural). For each country and industry, we calculate the average wage of R&D labor by dividing R&D labor expenditures by the corresponding number of full-time equivalent R&D personnel. These wages are then divided by the wage of the base country, yielding the relative price (PPP) for R&D labor.

This procedure implicitly assumes R&D personnel in different countries are equally productive, ascribing any differences in wages to higher labor cost, not to higher productivity. Data limitations prevent us from grouping employees by function or qualification and comparing their relative wages across countries before they are aggregated to form R&D labor PPPs. However, in the interviews, firm management stated that the biggest differences in compensation are across technical fields, and these variations are likely to be captured by average compensation in each industry. Firm officials also indicated that the skills of R&D personnel in routine development work, which constitutes the bulk of R&D, are quite similar across countries. This suggests that the tacit assumption that workers in each country have comparable qualities or capabilities may not be that far from the reality.[14] However, while this assumption may be realistic for the group of (advanced) countries we study here, much more caution would be necessary if countries like Mexico or China were included in a comparison.

A major hurdle in developing R&D compensation rates is the coverage of the U.S. R&D survey, which only collects data on the number of research scientists and engineers (RSEs) in its survey of business enterprises. In contrast to all other countries, there is no information on the number of support staff employed.[15] In order to determine the number of support personnel in the United States, we examined a wide range of alternative data sources. A careful assessment of this evidence suggests that the support share in an industry's total employment is a fair representation of its support share in R&D. More detail on this evidence, which was supported by the firm interviews, is described in McGuckin, van Ark, et al. (2004). In addition, our independent estimate of the U.S. share is in the range of that found for the other countries in this study.

Because only R&D personnel headcount is collected rather than full-time equivalents in Japan, the Japanese R&D labor price is probably understated. If part-time R&D personnel are counted as full time, then compensation per employee is underestimated. While this distinction may not be important in practice, one study made a large downward adjustment to the personnel count (National Science Foundation 1998). On the other hand, given Japan's typically higher working hours, the net effect of the part-time/full-time difference on average compensation may not be large.

14. This assumption is also supported by an insignificant correlation of labor price with the support share of R&D personnel at the industry level. The support share of R&D personnel provides a proxy for (basic) scientific and engineering skills and is the only comparable skill measure available outside the United States.

15. Information on the number of technicians is also not (explicitly) collected in the United States. However, we have found that most firms appear to make little distinction between RSEs and technicians and tend to include them in reported RSEs.

Other Inputs

Materials and supplies represent about 20 percent of R&D expenditure. The interviews suggest that the majority of expenditure in this category consists of prototypes of new products or, in other words, the products of the industry itself. Therefore, we use own-industry output PPPs, adjusted for margins so that they represent the purchase prices of own-industry goods used as inputs.[16] These prices come from industry-of-origin studies of item-level matches of industrial census data for specific industries in each country and are described further in section 10.4.

It was more difficult to identify prices for other current costs, and these are important at 24 percent of R&D expenditure. According to the firms we interviewed, this category includes an array of goods and services typically described as "overhead." Detailed financial data for about ten firms showed that this category includes such items as communications services, rent, utilities, and noncapital computers and instruments. We were able to identify industry-of-origin (ICOP) and final expenditure (ICP) price parities that matched many of these goods and services.[17] However, this information is not industry specific, so we implicitly assume that the relative prices of these overhead goods and services are similar across industries. While most goods purchased for use in R&D programs are obtained in national markets, they may not be used in the same proportions in all industries. Because we do not have any information about the expenditure shares within this category, we use an unweighted average of eleven price "headings."

For high-tech inputs such as computers, it is particularly difficult for the PPPs to take full account of quality differences. Because there is a wide spread in the prices of these inputs, the resulting price parity for this category is somewhat sensitive to what prices are included and excluded, especially in the case of Germany and Japan. Yet some simple experiments in which we removed outlying prices suggest that the impact on the aggregate R&D PPP is not that large (see McGuckin, van Ark, et al. 2004).

It was also difficult to develop prices for capital expenditures; they are, however, the smallest category of R&D expenditure, at 9 percent.[18] We fol-

16. Because output PPPs do not reflect transportation and distribution margins, we add these margins back in using information from input-output tables in order to treat these goods as purchased inputs to the industry.

17. For ICOP (intermediate) prices, this means that transportation and distribution margins are added back in, and for ICP (final expenditure) prices, tax margins are removed (peeled off). These margins are estimated using input-output tables.

18. In considering capital inputs, a number of additional difficulties arise. Some countries appeared to have quite low capital expenditures. This could be related to a greater tendency to own land, in which case the opportunity costs of owning are not accounted for (some interviews suggested this). To the extent that firms in other countries are more likely to lease land, capital expenditures could be misleading. Moreover, capital service flows based on appropriately valued capital stocks are the appropriate concept, but given data limitations, we

Table 10.3 R&D expenditure shares, total manufacturing, 1997

	Shares of total manufacturing R&D expenditure (%)						
R&D input category	France	Germany	Japan	The Netherlands	United Kingdom	United States	Average from interviews[b]
1. Labor compensation	52.8	61.7	42.7	52.1	37.0	46.5	46.7
2. Materials and supplies	16.9[a]	13.9[a]	20.3	14.7[a]	26.1	15.8	19.7
3. Other current costs	23.2	17.5	27.3	23.7	24.8	29.3	24.4
4. Capital expenditure	7.1	6.9	9.7	9.5	12.1	8.4[a]	9.2
Total R&D cost	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: National R&D surveys, National Science Foundation (2002), OECD (2003). See McGuckin, van Ark, et al. (2004) for more details.

[a]See text for description of assumptions made to determine weights.

[b]Average of 10 firms' expenditures that provided detailed financial data for total R&D in interviews.

lowed a similar approach to that used for other current costs and selected five ICOP and ICP price parities that correspond to plant and equipment headings appropriate for capital expenditures. Again, because we do not have an industry-level breakdown of capital expenditure, we implicitly assume that the proportions of capital inputs and relative prices of capital inputs used in each industry are similar across countries.

The assumption of common patterns and national markets seems more plausible for the other current and capital costs than for labor or materials. But the lack of systematic weights and potential quality-adjustment problems for the prices of current cost and capital items means that we are less confident about the PPPs for these inputs. Therefore, we explore some alternative R&D PPPs that use different proxies for these input categories. The most interesting of these uses the industry-specific material PPPs for all of the nonlabor inputs, while another uses the GDP PPP. These are described further in section 10.3.5.

Weights (Shares)

Weights for each of the four categories of inputs by country are shown in table 10.3. Each of these expenditure shares for total manufacturing is built up from expenditures of nineteen manufacturing industries in the national R&D surveys. As shown in the table, the expenditure shares from national statistics are in a similar range as those we obtained from firm interviews. In fact, if we compare the ten firms' financial information we obtained in interviews with corresponding industry expenditures shares in

can only consider current capital expenditure. Still, capital expenditures were rarely a large share of expenditure on R&D, so the results may not be substantially affected by these problems.

firms' home countries, their labor shares only differ by about 2 percent, on average.

There were two categories of expenditure where we had to make assumptions about the shares. First, expenditure information on materials and supplies is not collected in France, Germany, and the Netherlands. For these countries, we assigned the average of the United States, United Kingdom, and Japan's shares of nonlabor, noncapital expenditure. Second, the U.S. R&D survey only collects R&D depreciation, so it is not comparable with the other five countries' R&D capital expenditures. Moreover, because accounting requirements for R&D (at least in the United States) restrict the capitalization of R&D-specific assets, depreciation is likely to be quite different from even the average expenditure on capital. In fact, the U.S. depreciation share is far lower than the other countries' capital expenditure shares, at only 1.3 percent compared to the 9 percent average for the other countries. The 9 percent figure is also closer to the typical capital expenditures of the firms we interviewed. We therefore use the industry-specific average of the other five countries' capital expenditure shares as an estimate of the U.S. share. More details about the interviews and the basis for our assumptions about the R&D input prices and weights are described in McGuckin, van Ark et al. (2004).

10.3.3 Discussion of the Results

Table 10.4 provides estimates of the R&D PPP and the price level or cost of R&D for each country. These price levels represent the relative cost of a unit of R&D input in each country compared with the United States. R&D price levels are defined as the R&D PPP divided by the exchange rate of the country's currency relative to the U.S. dollar. These levels represent costs relative to the United States. If the PPP is the same as the exchange rate, the price level equals 100.

Based on these results for 1997, manufacturing R&D in Germany and

Table 10.4 R&D PPPs and R&D price levels (cost relative to the United States), total manufacturing, 1997

	France (€/$)	Germany (€/$)	Japan (¥/$)	The Netherlands (€/$)	United Kingdom (£/$)	United States ($/$)
R&D (lab+mat+OC+cap)	0.86	0.98	138.1	0.80	0.54	1.00
Exchange rates	0.89	0.88	121.0	0.88	0.61	1.00
R&D price level (U.S. = 100)	96.4	111.0	114.1	90.0	88.8	100.0

Sources: See sources to tables 10.2 and 10.3.

Notes: Exchange rates are year averages (EMU countries converted into Euro equivalents). R&D price levels are defined as R&D purchasing power parity (PPP) divided by the exchange rate of the country's currency relative to the U.S. dollar. These levels represent costs relative to the United States.

Table 10.5 **R&D input price levels (cost relative to the United States), total manufacturing, 1997**

Input category	France	Germany	Japan	The Netherlands	United Kingdom	United States
1. Labor compensation	84.9	97.6	93.9	76.4	58.9	100.0
2. Materials and supplies	118.1	129.9	101.0	117.5	149.3	100.0
3. Other current costs	102.0	133.2	161.3	95.0	107.1	100.0
4. Capital expenditure	108.8	119.1	103.3	118.4	105.2	100.0

Sources: See sources to table 10.2 and 10.3.

Notes: R&D price levels are defined as R&D purchasing power parity (PPP) divided by the exchange rate of the country's currency relative to the U.S. dollar. These levels represent costs relative to the United States.

Japan is 11 percent to 14 percent more expensive than in the United States, while in France, the Netherlands, and the United Kingdom, R&D is 4 percent to 11 percent less expensive. Because the expenditure weights are relatively similar across countries, these cost differentials are driven by the differences in the relative prices of input categories. Comparative price levels for each R&D input category are shown in table 10.5 for total manufacturing. Lower prices in France, the Netherlands, and the United Kingdom can be traced to lower R&D labor prices. The higher prices in Germany and Japan are attributable to the high price of other current costs, or overhead, expenses. For both countries, wholesale and retail trade and transportation and storage have the highest relative prices (McGuckin, van Ark, et al. 2004). In Japan, insurance is also relatively expensive, while in Germany, electricity, gas, and water are relatively costly.

The approximate magnitude of the price differences that we observe using these newly constructed R&D PPPs are similar in character to those reported in the interviews. In most cases, the cost of performing routine R&D was described as not varying all that much across the countries included in this study. The differences we measure for total manufacturing in the 5–15 percent range are consistent with these observations.

Labor Prices and Interindustry Variation

Because labor represents the largest share of R&D and the data are R&D and industry specific, it is worth examining the labor PPPs more closely. Interviews suggest that R&D labor compensation can vary widely between technical fields and that the mix of technical fields varies greatly from firm to firm and from industry to industry. Labor costs do vary considerably across industries and, particularly, across countries, even within industries.

Due to shortage of space, this paper does not show the results for the nineteen individual manufacturing industries.[19] Interindustry variation is illustrated by the coefficients of variation (CV) for price levels of R&D labor relative to the United States. These are especially wide for the Netherlands and the United Kingdom, where the CVs are 0.38 and 0.40, respectively.[20] In contrast, France has the narrowest range of relative labor-price levels across industries, with a CV of 0.16. An important question is whether the differences across industries are larger or smaller than the differences across countries. We performed a two-way analysis of variance (ANOVA) and found significant differences across both industries and countries, with more of the variation coming from across countries than from across industries. One explanation for the importance of the country effect is national policies and union negotiations in most of the European countries. The large differences in R&D labor prices across both countries and industries illustrate the importance of including R&D labor explicitly in R&D PPPs.

Nonlabor Input Prices

The three remaining categories of input prices used for the construction of the R&D PPPs are materials, other current costs, and capital expenditures. Only the materials prices are industry specific. The variation in relative price levels across industries for materials is nearly as large as that for labor. The coefficient of variation across industries for each of the five comparison countries is between 0.20 and 0.42. As with labor, an ANOVA analysis shows that the differences across both industries and countries are statistically significant.

R&D PPPs for 1987

Using the same methods and data sources, we also derive relative prices in 1987 for the same four categories of R&D inputs and aggregate them using R&D expenditure weights. Although for some countries the source material is less extensive and detailed (in particular for the Netherlands), we are able to follow very similar procedures. The results of this exercise at the level of total manufacturing are shown by country in table 10.6.

Comparing the relative R&D price levels for 1987, we observe that the United Kingdom is least expensive, 22 percent cheaper than the United States, and France, Germany, and the Netherlands are most expensive, at 6 percent to 16 percent more costly than the United States; Japan is nearly tied with the United States. The lower R&D prices in the United Kingdom are driven most importantly by lower R&D labor prices, while higher

19. See table B6 in McGuckin, van Ark, et al. (2004).

20. Coefficients of variation are calculated as the standard deviation divided by the unweighted arithmetic mean of the relative price levels of R&D labor by industry.

Table 10.6 **R&D PPPs and R&D price levels (cost relative to the United States), total manufacturing, 1987**

	France (€/$)	Germany (€/$)	Japan (¥/$)	The Netherlands (€/$)	United Kingdom (£/$)	United States ($/$)
R&D (lab+mat+OC+cap)	0.99	1.06	141.1	0.97	0.48	1.00
Exchange rates	0.92	0.92	144.6	0.92	0.61	1.00
R&D price level (U.S. = 100)	107.7	115.9	97.5	105.9	77.7	100.0

Sources: See sources to table 10.2 and 10.3 and McGuckin, van Ark, et al. (2004).
Notes: See notes to table 10.4.

Table 10.7 **R&D input price levels (cost relative to the United States), total manufacturing, 1987**

Input category	France	Germany	Japan	The Netherlands	United Kingdom	United States
1. Labor compensation	92.0	110.8	83.1	89.7	48.4	100.0
2. Materials and supplies	128.3	121.9	100.4	112.5	111.2	100.0
3. Other current costs	118.5	121.5	116.2	114.1	104.5	100.0
4. Capital expenditure	129.9	125.2	102.3	141.9	115.3	100.0

Sources: See sources to table 10.2 and 10.3 and McGuckin, van Ark, et al. (2004).
Notes: See notes to table 10.5.

prices in France, Germany, and the Netherlands can be linked to the high price of capital. The relative price levels for the input categories are shown in table 10.7.

10.3.4 Sensitivity of the R&D PPP: Alternative Measures

An important question for the interpretation of our results is how sensitive the R&D PPPs are to the assumptions we make. In general, our R&D PPPs will be more accurate if the underlying relative prices are well-measured, if they refer specifically to R&D in each industry, and if there are industry-specific weights to combine them into a single index. Of the four R&D input categories, we are most confident in our measure of the price of R&D labor as it is collected specifically for R&D within each industry and country and is nearly comprehensive across countries.[21] As mentioned before, though, a drawback is the lack of a breakdown by labor type. The materials inputs are next best as they are industry specific, and the coverage in each industry is high although they are not R&D specific.

21. This discussion abstracts from various issues associated with the R&D survey design. In particular, the collection of expenditure data at the firm level coupled with the classification of a firm into a single industry means that for diversified firms the industry numbers involve a mix of industries.

Table 10.8 **Selection of input price measures for alternative versions of R&D PPP, by input category**

	Price measure			
R&D input category	Preferred (a)	Alternative (b)	Alternative (c)	Current practice (d)
1. Labor compensation	Labor	Labor price parity	Labor price parity	GDP PPP[a]
2. Materials and supplies	Materials	Materials price parity	GDP PPP[a]	GDP PPP[a]
3. Other current costs	Other current	GDP PPP[a]	GDP PPP[a]	GDP PPP[a]
4. Capital expenditure	Capital	GDP PPP[a]	GDP PPP[a]	GDP PPP[a]
Name of alternative	lab+mat+OC+cap	lab+mat+GDP	lab+GDP	GDP

Notes: Price parity is price of good in comparison country divided by price of same good in base country (United States). The labor price parity and materials price parity are available at the level of specific industries.

[a]Categories with the same price measure use the total weight of the merged categories for R&D PPP aggregation.

As discussed in section 10.3.2, the prices for other current costs and capital costs in the preferred R&D PPP construction are more problematic. Here we have a limited number of individual item prices, some of which could be improved with hedonic quality adjustments and no weights for the prices that make up the input categories. Although the choices of price proxies were informed by interviews of R&D-intensive firms, we are less confident about these prices because they are not quality-adjusted, there are no weights, and the available price data is relatively sparse.

In many respects the choices we face are simply echoes of the earlier studies. But here we develop several alternative versions of the R&D PPP and use them to ascertain the sensitivity of the resulting R&D PPP. The specific input prices used in developing these alternative R&D PPP estimates are described in table 10.8.[22]

In addition to our "preferred" R&D PPP discussed previously, labeled (a), we estimate two other versions, labeled (b) and (c), in addition to the current practice labeled (d). The alternatives discussed here use the same industry-specific measure of the price of R&D labor. They also use the same weights for the individual inputs. Only the prices used for the input categories are varied. We compare these different versions of the R&D PPP to understand the sensitivity of the results to the selection of price proxies for the input categories.

Both alternative R&D PPPs are roughly based on the concept of the Griliches-Jaffe R&D deflator, which combines the price of labor with a

22. We estimated several other variants as well, making a variety of different assumptions about the prices used for other currency and capital costs. The result of these variants was in each case similar to either alternative (b) or (c), so they are not shown here.

broader measure of economywide price changes (Jaffe 1972; Griliches 1984).[23] Alternative (b) uses industry-specific PPPs for materials and supplies to reflect the cost of prototypes and associated goods. For other current costs and capital expenditure, it borrows from the current practice of using the GDP PPP. This approach makes the assumption that the relative price levels of other current and capital R&D costs equal the average relative price level for the aggregate economy. This alternative is referred to as "lab+mat+GDP," and because it is strongly industry specific, we consider it to be the most conceptually appropriate alternative to our preferred measure.

Alternative (c) uses the GDP PPP to proxy the price of all nonlabor inputs, including materials and supplies. This alternative is referred to as "lab+GDP," and it combines industry-specific R&D labor with economywide GDP final goods prices. Finally, we compare the results with the current practice alternative (d), which uses the GDP PPP for all R&D inputs and is widely used by statistical agencies and national science authorities for international comparisons of science and technology indicators. As argued in the preceding, use of GDP is particularly problematic as it includes a wide range of products and services not used in R&D, and the concept is based on final expenditure.

The use of these alternatives obviously does not cover the entire range of possible measurement problems. Although we do not have systematic quantitative estimates of potential error, we examine here several simple changes in assumptions within each of the alternative estimates to see if they produce major changes in the resulting R&D PPP. For instance, we have excluded some outliers from the set of prices we use for other current costs in calculating our preferred R&D PPP for Germany and Japan. This results in a drop in the input prices in the range of 6–13 percent relative to the United States. But in such instances, the resulting R&D PPPs are only affected by 1.0–3.5 percent. This result is typical of the tests we have conducted.

When we use the Fisher PPP aggregation formula described in section 10.3.1 to aggregate prices across countries, large differences in the underlying weights in fact imply a wide range of possible outcomes. This range is referred to as the *Paasche-Laspeyres spread* and is usually large when countries have very different price structures. Because the six countries in this comparison are at a similar level of development, we did not expect that this should be a significant problem, and it is not. The Paasche-Laspeyres

23. The Griliches-Jaffe deflator originally referred to a proxy R&D price index for the United States that combined the hourly compensation index with a 51 percent weight and the implicit deflator for nonfinancial corporations with a 49 percent weight (Griliches 1984). We analogize this interpretation to spatial comparisons by using PPPs instead of deflators and extend it to use industry-specific R&D labor prices and weights from actual R&D expenditure shares.

Table 10.9 **Comparison of price levels (cost relative to the United States) using preferred R&D PPPs and alternative R&D PPPs, total manufacturing, 1997**

R&D PPP version	France	Germany	Japan	The Netherlands	United Kingdom	United States
Preferred						
(a) R&D (lab+mat+OC+cap)	96.4	111.0	114.1	90.0	88.8	100.0
Alternatives						
(b) R&D (lab+mat+GDP)	98.2	106.4	109.0	90.1	88.0	100.0
(c) R&D (lab+GDP)	97.3	104.1	114.7	88.0	81.7	100.0
Current practice						
(d) GDP (GDP PPP)	111.4	112.3	134.7	100.9	103.2	100.0
Difference between (a) and (b)	1.8	–4.6	–5.1	0.1	–0.7	
Difference between (a) and (c)	0.9	–6.9	0.6	–2.0	–7.1	
Difference between (a) and (d)	14.9	1.3	20.6	10.9	14.5	

Sources: See sources to tables 10.2 and 10.3.
Note: Alternative R&D PPPs are described in table 10.8.

spread is on the order of 2–3 percent for most comparisons, suggesting that differences in the weights are not large enough to meaningfully affect the comparisons. Moreover, we anticipate that measurement errors in the underlying prices will affect the results more than any differences in the weights, which are R&D and industry specific.[24]

Alternative Versions of the R&D PPP at the Country Level, 1997

Table 10.9 reports the different versions of relative price levels based on various R&D PPPs, labeled (a) through (c), and the alternative (d), the GDP PPP that is used in current practice. As discussed previously, these alternatives make different assumptions about what prices to use to represent nonlabor R&D input prices. The price levels based on the alternative R&D PPPs (b) and (c) are quite similar to the one using our preferred R&D PPP (a). They differ by –7.1 to +1.8 percentage points from the preferred specification (a) for each country. Alternative R&D PPP (b) "lab+mat+GDP" yields results that are within 5 percentage points of the preferred R&D PPP (a), while alternative (c) "lab+GDP" yields results within about 7 percentage points of (a). Recall that both alternatives (b) and (c) are based on a Griliches-Jaffe-type R&D PPP. In particular alternative (c) is relatively straightforward to compute as it only requires a PPP for R&D labor and a GDP PPP.

In sharp contrast, the current practice of using the GDP PPP by itself

24. The issue of measurement errors in international pricing programs, such as the ICP program or the ICOP project, is discussed extensively elsewhere. For a discussion of measurement issues related to the expenditure-based ICP program, see the "Castles Report" (OECD 1997). For a review of industry-of-origin studies of PPPs and productivity, see van Ark (1993) and van Ark and Timmer (2001).

yields substantially different results from the preferred measure. Compared to the preferred R&D PPP (a), current practice version (d) varies by 12.4 percentage points on average and by as much as 20.6 percentage points in the case of Japan. Only for Germany are the results within the range of the other alternatives. The size of these differences suggests that the use of an R&D PPP will yield comparative costs and R&D intensities that vary substantially from the current practice of using GDP PPPs, likely increasing the real R&D performance of the comparison countries relative to the United States.

Alternative R&D PPPs at the Industry Level, 1997

When comparing the preferred R&D PPP (a) with alternative (b) that uses fully industry-specific input price data at the level of individual industries, the coefficients of variation across industries are about the same for both R&D PPP versions, and we see similar significant differences across industries and countries under an ANOVA analysis. The price levels are significantly determined by the price of R&D labor, which both preferred version (a) and alternative (b) contain in equal proportions. Therefore, it is not surprising that the simple correlation between the two sets of price levels (a) and (b) is 0.83. If we correlate the industry-specific prices with GDP PPPs by themselves, the correlation is only about 0.59.

These results suggest that it is important that the R&D PPP be industry specific, but that it is less essential that a full R&D PPP be developed for all input categories in a specific year. Given the current uncertainties in measurement of the R&D PPP for other current cost and capital expenditure, the alternatives (b) and (c) that combine R&D-specific measures of the price of labor (and preferably also material prices) with output prices performs very similarly to a fully developed R&D PPP. These results are consistent with analogous findings about the importance of measuring R&D labor prices in the time dimension in studies by Mansfield (1987) and Jankowski (1993).

Alternative Versions of the R&D PPP, 1987

In order to assess how much the 1987 R&D-specific PPPs differ from the current practice of using the GDP PPP as a substitute, we also compared the preferred R&D PPP and several alternatives with the GDP PPP, just as we did for the 1997 PPPs.[25] Again, the alternative R&D PPPs are quite similar to the preferred R&D PPP. The alternative PPPs for the European countries differ by no more than 7 percentage points from the preferred PPPs. The gap for Japan is somewhat larger, with R&D PPP alternative (c) "lab+GDP" differing by 17 percentage points from the preferred PPP. However, for all countries, the GDP PPP (d) yields quite different results

25. See McGucken, van Ark, et al. (2004), table A4.

from any of the other measures. As with the 1997 values, there is substantial variation across industries and great similarity in the coefficients of variation between R&D PPP versions (a) and (b). Arguably, alternative (a) is too difficult to calculate systematically on a year-by-year basis, but it is relatively straightforward to obtain (b) and in particular (c), and these alternatives provide R&D price levels that correspond reasonably close to the preferred ones. We will return to this issue in our closing comments.

10.3.5 Comparing the Distribution of Relative Prices over Time

Having made two benchmark estimates, it is tempting to use them to compare the change in relative price levels of each country vis-à-vis the United States over time. In principle, such comparison should give more reliable results because even though the relative price levels are measured with some error in each benchmark year, they tend to cancel out for measures of change over time provided the errors come from the same sources in each year. Such an argument is often invoked in the context of discussions of productivity growth estimates (for example, Hulten 2001). However, even when basic price and quantity data for the benchmark PPPs and time series are consistent, two index number problems plague a comparison of PPPs for two different benchmark years. The first problem is that for a comparison between two points in time, the weights need to be held fixed. The second element relates to the fact that the time series are typically based on national weights of each individual country, whereas benchmark estimates are based on a common weighting system for both countries. Both weighting problems are well-known in the price-index number literature and have been called the "tableau effect" by Summers and Heston (1991).[26]

Despite these difficulties, it is informative to compare the change in our R&D PPPs between 1987 and 1997 to the change in GDP PPPs over the same period. While the period considered is relatively short and the levels of development across countries are not too different, comparisons of PPP results from two different benchmark years will only lead to relatively minor inconsistencies when price and quantity structures remain rather stable.

In table 10.10 we show the change in the R&D PPPs for total manufacturing for the preferred construction, alternative (b) "lab+mat+GDP" PPPs and the change in the GDP PPPs.[27] The table shows that while the sign of the change in the PPPs is the same for each alternative PPP, the magnitudes differ considerably, even between our preferred measure (a) and

26. Conceivably, an appropriate weighting system should exist (something akin to chain-weighted or so-called spanning trees) that could remedy these inconsistencies, but an exploration of this issue is beyond the scope of this paper. See, for example, Hill (2004).

27. We do not show changes in relative price levels here as those include both changes in the PPPs and changes in exchange rates and are therefore more difficult to interpret.

Table 10.10 Changes of R&D PPPs for total manufacturing and GDP PPPs between 1987 and 1997

	Preferred (a): lab+mat+OC+cap			Alternative (b): lab+mat+GDP			Current practice (d): GDP PPP		
Country	1987	1997	Change (%)	1987	1997	Change (%)	1987	1997	Change (%)
France	1.02	0.86	–16.8	0.99	0.87	–12.4	1.04	0.99	–4.5
Germany	1.08	0.98	–0.7	1.08	0.94	–14.0	1.13	0.99	–12.6
Japan	159.1	138.1	–14.2	172.8	131.9	–27.0	210.2	163.0	–25.4
The Netherlands	0.95	0.80	–17.4	0.92	0.08	–14.5	1.06	0.89	–17.2
United Kingdom	0.56	0.54	–2.8	0.53	0.54	1.8	0.56	0.63	11.1
United States	1.00	1.00	0.0	1.00	1.00	0.0	1.00	1.00	0.0

Sources: See sources to tables 10.2 and 10.3 and McGuckin, van Ark, et al. (2004).
Notes: Percent changes are log differences. Exchange rates are annual averages.

alternative (b). But on average the difference between the two R&D PPPs is smaller than the difference between the R&D PPPs and the GDP PPPs. These results suggest that the current practice of using GDP PPPs over time will be biased compared to using dedicated R&D PPPs, with the direction of the bias varying by country and industry. In addition, it calls into question using GDP deflators to compare R&D expenditure over time as suggested by Jankowski (1993) on the basis of U.S. data that are now over ten years old. These results suggest that the development of dedicated R&D deflators could be worthwhile.

10.4 Real R&D Intensities

As mentioned in the introductory section, the ratios of R&D expenditure to GDP or national income are a key focus of policy discussions across the world and are often used as comparative measures of the intensity of the efforts devoted to innovative activities. Because such comparisons of R&D intensities often rely on nominal figures to make comparisons, this is an application where properly adjusting for price differences may have a substantial impact. We therefore examine the effect on R&D intensities of adjusting for differences in R&D prices as well as output prices at the level of total manufacturing and for individual industries. While we cannot directly apply the R&D PPPs we develop in this study to economywide R&D—as the nonmanufacturing R&D could be quite different and almost 36 percent of private U.S. R&D was outside of manufacturing in 1999—the differences between nominal and real R&D intensities that we observe should be indicative of the dangers that may exist with current practice for similar measures covering the aggregate economy.

10.4.1 Adjusting R&D Intensities for Differences in Price Structure

Real R&D intensity measures require that R&D expenditure be deflated by an R&D PPP and output by an appropriate output PPP. In this paper we have developed preferred and alternative R&D PPPs. Here we use the preferred one. For output, the PPPs come from industry-of-origin studies conducted in the ICOP project at the University of Groningen. These output PPPs, or more appropriately unit value ratios (UVRs), are calculated using data on quantities and values of output from production censuses and industrial surveys. Individual products are matched across countries and then weighted to form industry-specific and—after aggregation—manufacturing-wide PPPs.[28]

Quality Adjustments for Output PPPs

As with all price measurement, adequately taking into account the differences and changes in quality of products is a difficult undertaking. Moreover, as with other price indexes, research on quality adjustment has generally focused on comparing constant-quality prices over time, rather than constant-quality prices across countries.[29] Exceptions are the work of Danzon and Chao (2000), Konijn, Moch, and Dalén (2003) and van Mulligen (2003). Danzon and Chao (2000) estimate PPPs for pharmaceuticals, Konijn, Moch, and Dalén (2003) estimate computer PPPs, and van Mulligan (2003) estimates automobile PPPs. Of these studies, only the work of van Mulligen (2003) fits well into the industry-of-origin approach as it compares prices of cars that are *produced* in a country. The other two studies examine the bundle of goods *purchased* in that country.

For our output PPPs, we therefore only make use of the automobile PPPs constructed by van Mulligen (2003). The main difference with standard UVRs based on the (producer) unit value per average car is that these PPPs take into account the fact that cars produced in the United States generally have more horsepower and are larger than those produced in Europe or Japan. Van Mulligen uses power and length characteristics of vehicle models to estimate quality-adjusted PPPs using hedonic methods. Unadjusted conversion factors are shown to be biased downward by as much as 50 percent relative to the United States.

It is much harder to gauge what the likely effects would be of quality-adjusted PPPs for other products such as computers or telecom equip-

28. For a more extensive general description of this method, see van Ark (1993) and van Ark and Timmer (2001). For the European manufacturing UVRs PPPs used in this study, see O'Mahony and van Ark (2003). For the Japan-U.S. PPPs, see Inklaar, Wu, and van Ark (2003). Aggregation follows similar procedures as described earlier in the case of R&D PPPs.

29. For a survey of quality change over time for non-R&D products, see Lebow and Rudd (2003). For literature on cross-country quality measurement, see van Ark (1993) and van Mulligen (2003).

ment. A complicating factor is that many of these high-tech goods are not produced in all countries. In a series of comparisons of productivity for manufacturing industries by the McKinsey Global Institute, quality adjustments were made on an industry-by-industry basis mostly on the basis of proprietary information or by using expert judgments on the quality of comparable products (McKinsey Global Institute 1993; Gersbach and van Ark 1994). Although quality adjustments could be considerable for particular products, we have not used this information as it is only available for a limited number of industries, relating to the early 1990s and covering only Germany, Japan, and the United States.[30]

Real R&D Intensities and Ranking

The nominal and real R&D intensities at the level of total manufacturing are shown in table 10.11 for 1987 and 1997. The nominal R&D intensity is in the first column, the real R&D intensity in the second, and the difference between the real and the nominal intensities in the third.[31] The real R&D intensity is calculated by using R&D PPPs to deflate nominal R&D expenditure and using output PPPs to convert manufacturing gross output to a common currency. The difference between the real and nominal intensities can therefore be traced to these two adjustments.

In table 10.11, the nominal R&D intensity is defined as manufacturing R&D expenditure divided by manufacturing gross output, as gross output is the correct measure for sectoral analysis. Because international comparisons often are made using GDP, we also replicated all the analysis using R&D intensities based on value added as the output measure. Table B21 in McGuckin, van Ark, et al. (2004) show these results. The magnitude of the value-added-based intensities is roughly three times higher because the value-added measure omits intermediate inputs. The main results of the analysis, reported in the following, are the same irrespective of the output measure used.

The U.S. R&D intensity is highest in all cases, even after the PPP adjustments described in the preceding. The typical adjustment, using R&D and output PPPs, to each of the comparison countries is positive and sizable, yielding R&D intensities that are closer to the U.S. level than under current practice, and this is true for both 1987 and 1997.[32] These results

30. For example, for personal computers the different composition of products produced in Germany and the United States led to an upward adjustment of the census-based German-U.S. computer output PPP by 41 percent in 1990. The PPP for audio and video equipment (including telecom equipment) was only adjusted upward by 5.1 percent. At more aggregate levels (e.g., for total manufacturing), these effects are likely to be much smaller as quality adjustments for some other industries may bias the PPP in the opposite direction (Gersbach and van Ark 1994).

31. The results described here are based on the preferred R&D PPP. If the alternative R&D PPP is used instead of the preferred R&D PPP, the difference between the nominal and real R&D intensities is similar, and the changes in rank are identical.

32. Because the United States is the base country, the U.S. intensity does not change with the PPP adjustment.

Table 10.11 **Nominal and real R&D intensity for total manufacturing (R&D/gross output) using preferred R&D PPP and output PPPs**

	Current practice	With R&D PPP and output PPP Adjustments	
Country	Nominal	Real	Difference
	Year 1987		
France	2.06	2.47	0.42
Germany	2.71	2.87	0.16
Japan	2.24	2.75	0.51
The Netherlands	2.04	2.21	0.17
United Kingdom	2.07	3.09	1.03
United States	3.44	3.44	0.00
	Year 1997		
France	2.22	2.40	0.18
Germany	2.50	2.47	–0.02
Japan	2.89	2.95	0.06
The Netherlands	1.59	1.74	0.16
United Kingdom	1.92	2.49	0.57
United States	3.12	3.12	0.00
	Change from 1987 to 1997		
France	0.16	–0.07	–0.24
Germany	–0.21	–0.40	–0.18
Japan	0.65	0.20	–0.45
The Netherlands	–0.46	–0.47	–0.01
United Kingdom	–0.15	–0.61	–0.46
United States	–0.32	–0.32	0.00

Sources: See sources to tables 10.2 and 10.3. Gross output based on OECD (2004). Output PPPs based on O'Mahony and van Ark (2003) and Inklaar, Wu, and van Ark (2003) for 1997, and van Ark (1993) for 1987.

Notes: Adjustments for R&D PPP divide R&D expenditures by the R&D PPP. Adjustments for output PPP divide gross output by an output PPP. Real intensity includes both adjustments.

suggest that the efforts devoted to R&D in each country are more similar across countries than is apparent using the nominal R&D intensities that are currently the norm.

The effect of the price adjustments on R&D intensity is particularly large for the United Kingdom: Before adjustment (in nominal terms), its R&D intensity is only 2.1 percent in 1987 and 1.9 percent in 1997. After adjustment for relative prices of R&D and gross output, the U.K.'s R&D intensity (in real terms) is much higher at 3.1 percent in 1987 and 2.5 in 1997. In 1987, these adjustments shift the rank of the United Kingdom from next to last among the six countries in this study to second place after the United States, displacing Germany and Japan. The R&D PPP contributed about two-thirds of the adjustment in that year.

Not only are the levels of R&D intensity affected by price adjustments, but so are the *changes* in R&D intensity. From 1987 to 1997, nominal R&D intensity in Germany dropped by 0.2 percentage points. Using real R&D intensity, however, the drop was 0.4 points. In general, R&D PPPs declined less than output PPPs, worsening the trend in R&D intensity between 1987 and 1997.

Real R&D Intensities for Individual Industries

R&D intensities for individual industries are subject to the same interpretation problems as those at more aggregate levels due to the use of nominal values. Using industry-specific R&D PPP and output PPP price adjustments to adjust nominal industry-level R&D intensities gives real R&D intensities for individual industries. As a result of the large variation in (i) the R&D PPPs (because of large R&D labor-price variation), (ii) output PPPs, and (iii) nominal R&D intensities across industries, these adjustments are often larger in percentage points than those at the total manufacturing level. The average difference between real (PPP adjusted) R&D intensities and nominal R&D intensities is 0.7 percentage point at the industry level, while for total manufacturing this is only 0.3 percentage points.

A key question for the interpretation of these differences is how important the adjustment for differences in relative R&D and output prices is compared to the differences in nominal R&D intensity. A two-way ANOVA between real and nominal R&D intensity among the six countries and nineteen industries demonstrates that the variation among industries is very large and statistically significant, while differences across countries are relatively small and not statistically significant. The variation among industries is likely attributable to the differences in technologies and R&D production functions and to demand-side opportunities that generate differences in the intensity of R&D efforts across industries. The smaller differences across countries are most likely a result of internationalization of R&D and increased competitiveness due to globalization.

10.5 Concluding Comments

This paper develops R&D PPPs that are conceptually appropriate in that they are based on relative prices for a basket of R&D inputs. To the extent that current data allows, we have developed R&D-specific prices and weights and aggregated them into R&D PPPs for nineteen individual manufacturing industries covering the years 1997 and 1987. Previous R&D PPP estimates did not utilize such detailed R&D-specific price and weight data as in this study, nor did they use interviews to guide the application of their methodology. Thus the R&D PPPs we developed allow us to better evaluate the importance of having R&D-specific measures of R&D price across countries.

A comparison of our preferred R&D PPPs with GDP PPPs suggests that current procedures for comparing R&D across countries are flawed. While there is some netting of industry differences at the economywide level, the GDP PPPs still differ substantially from R&D PPPs. At the industry level, use of the GDP PPP as a proxy for the R&D PPP is inappropriate. The differences between R&D PPPs and GDP PPPs are large, and a substantial fraction of these differences can be traced to variations in the price of R&D labor across industries.

The size of this difference and the relatively complex nature of our preferred R&D PPP has led us to consider two alternatives that can be readily calculated and could easily be adopted by statistical agencies. These relatively easy-to-measure alternative R&D PPPs are based on a Griliches-Jaffe-type index and are relatively close to the preferred R&D PPP in approximating differences in R&D price across countries and industries. The most plausible alternative measure combines industry-specific R&D labor PPPs and industry output PPPs for materials and supplies with the GDP PPP for other inputs.

While the most important source of differences at the economywide level is still R&D labor cost, prices of the other inputs to R&D can and do vary across industries. So by advocating that priority needs to be given to develop R&D labor PPPs, we are not suggesting that price measurement for other inputs to R&D should be ignored. For comparisons over time, few substitutes for our preferred R&D PPP are available. While industry-level changes in the preferred R&D PPP over time correlate well with those of the alternative R&D PPPs, differences at the total manufacturing level are large enough to cause significant errors of interpretation in not only R&D expenditures, but also in R&D intensities. This suggests that periodic benchmark estimates of the preferred R&D PPP would be useful to ensure that an alternative R&D PPP that relies mainly upon variations in R&D labor prices maintains a solid grounding over time.

Our results in the interspatial domain also suggest that intertemporal R&D deflator work should be given further attention. We find important differences between changes in the GDP PPP and the R&D PPPs. While one cannot draw direct conclusions regarding the development of relative prices due to different weighting systems at varying points in time, the results suggest that it would be useful to reexamine Jankowski's (1993) finding of a correlation between the GDP and the R&D deflator. One reason is that his study is now over ten years old, and there have been vast changes in economic structure and measurement of quality change. There is also evidence that this correlation does not hold up as well in other countries.[33]

33. For instance, Bernstein (1986) found that the GDP price deflator did not correspond well with an input-based R&D price deflator for Canada. Cameron (1996) found a similar result for the United Kingdom.

Moreover, given the lack of strong conceptual roots in using GDP as a measure of R&D price, internationally consistent R&D deflators should be further examined in the time domain.

Finally, we consider it vital that research be continued in this area. Our study is the first to examine R&D PPPs at the industry level and the only study that has been able to take advantage of the recently developed measures of comparable prices at the output level from the University of Groningen's ICOP program. Further improvements in price measurement and ongoing harmonization of R&D statistics and survey instruments could facilitate the construction of future comparisons and render them more reliable. Rapid growth of global R&D activities makes it vital that accurate comparisons be made of R&D, regardless of where it is performed.

References

Bernstein, J. 1986. *Price indexes for Canadian industrial research and development expenditures.* Montreal, Canada: Statistics Canada.

Brunner, E. D. 1967. *The cost of basic scientific research in Europe: Department of Defense experience, 1955–1966.* Report for United States Air Force Project. Santa Monica, CA: RAND.

Cameron, G. 1996. On the measurement of real R&D: Divisia price indexes for U.K. business enterprise R&D. *Research Evaluation* 6 (3): 215–19.

Conference Board, The. 1976. *Overseas research and development by United States multinationals, 1965–1975: Estimates of expenditures and a statistical profile.* New York: The Conference Board.

Danzon, P. M., and Chao, L. W. 2000. Cross-national price differences for pharmaceuticals: How large, and why? *Journal of Health Economics* 19:159–95.

DiMasi, J. A., R. W. Hansen, and H. G. Grawbowski. 2003. The price of innovation: New estimates of drug development costs. *Journal of Health Economics* 22:151–85.

European Commission. 2002. *Presidency conclusions—Barcelona European Council.* http://www.europa.eu/european_council/conclusions/index_en.htm.

Fraumeni, B., and S. Okubo. 2005. R&D in the National Income and Product Accounts: A first look at its effect on GDP. In *Measuring capital in the new economy,* ed. C. Corrado, J. Haltiwanger, and D. Sichel, 275–316. Studies in Income and Wealth, vol. 65. Chicago: University of Chicago Press.

Freeman, C., and A. Young. 1965. *The research and development effort in Western Europe, North America and the Soviet Union: An experimental international comparison of research expenditures and manpower in 1962.* Paris: Organization for Economic Cooperation and Development.

Gersbach, H., and B. van Ark. 1994. Micro foundations for international productivity comparisons. Research Memorandum no. GD-11. Groningen, The Netherlands: Groningen Growth and Development Centre.

Griliches, Z. 1984. *R&D, patents, and productivity.* Chicago: University of Chicago Press.

———. 1994. Productivity, R&D and the data constraint. *American Economic Review Papers and Proceedings* 84 (1): 1–23.

Hill, R. 2004. Constructing price indexes across space and time: The case of the European Union. *The American Economic Review* 94 (5): 1379–1410.
Hulten, C. R. 2001. Total factor productivity: A short biography. In *New developments in productivity analysis,* ed. C. R. Hulten, E. R. Dean, and M. J. Harper, 1–47. Studies in Income and Wealth, vol. 63. Chicago: University of Chicago Press.
Inklaar, R., Wu, H. X., and van Ark, B. 2003. Losing ground: Japanese labour productivity and unit labour cost in manufacturing in comparison to the U.S. Groningen Growth and Development Centre Research Memorandum no. 64. http://www.ggdc.net/pub/gd64.shtml.
Jankowski, J. E. 1993. Do we need a price index for industrial R&D? *Research Policy* 22:195–205.
Jaffe, S. A. 1972 A price index for deflation of academic R&D expenditures. National Science Foundation Report no. NSF 72-310. Washington, DC: Government Printing Office.
Jorgenson, D., and M. Kuroda. 1992. Productivity and international competitiveness in Japan and the U.S., 1960–1985. *Economic Studies Quarterly* 43 (2): 313–25.
Kiba, T., Sakuma, I., and Kikuchi, J. 1994. Development of R&D purchasing power parities. NISTEP Report no. 31. Tokyo: National Institute of Science and Technology Policy, March. http://www.nistep.go.jp/achiev/ftx/eng/rep031e/text/rep031e.txt.
Konijn, P., Moch, D., and Dalén, J. 2003. Comparison of hedonic functions for PCs across E.U. countries. Eurostat Discussion Paper. http://www.ifcommittee.org/konijn.pdf.
Kravis, I., Heston, A., and Summers, R. 1982. *World product and income: International comparisons of real gross product.* Baltimore: Johns Hopkins University Press.
Lebow, D. E., and Rudd, J. B. 2003. Measurement error in the Consumer Price Index: Where do we stand? *Journal of Economic Literature* 41 (1): 159–201.
MacDonald, A. S. 1973. Exchange rates for national expenditure on research and development. *The Economic Journal* 83 (330): 476–94.
Mansfield, E. 1987. Price indexes for R&D inputs, 1969–1983. *Management Science* 33 (1): 124–29.
———. 1988. The speed and cost of industrial innovation in Japan and the U.S.: External vs. internal technology. *Management Science* 34 (10): 1157–68.
McGuckin, R. H., R. C. Inklaar, B. van Ark, and S. M. Dougherty. 2004(a). The structure of business R&D: Recent trends and measurement implications. Conference Board Working Paper. http://www.conference-board.org/economics/workingpapers.cfm.
McGuckin, R. H., B. van Ark, S. M. Dougherty, and R. C. Inklaar. 2004(b). Appendices to the report on internationally comparable science, technology, and competitiveness indicators (revised). National Science Foundation Report no. SRS00-99594. http://www.conference-board.org/economics/workingpapers.cfm.
McKinsey Global Institute. 1993. *Manufacturing productivity.* Washington, DC: McKinsey & Company.
Mulligen, P. H. van. 2003. *Quality aspects in price indices and international comparisons: Applications of the hedonic method.* Voorburg, The Netherlands: Statistics Netherlands.
National Science Foundation. 1998. *The science and technology resources of Japan: A comparison with the United States.* NSF Special Report no. 96-324. Washington, DC: NSF. http://www.nsf.gov/sbe/srs/nsf97324/start.htm.

———. 2002. *Science and engineering indicators.* Washington, DC: NSF.
Organization for Economic Cooperation and Development. 1963. *Frascati manual—Standard practice for surveys of research and experimental development.* The Measurement of Scientific and Technological Activities Series. 1st ed. Paris: OECD.
———. 1979. Price indexes and R&D exchange rates. In *Trends in industrial R&D in selected member countries: 1966–1975,* 158–69. Paris: OECD.
———. 1981. *Frascati manual—Standard practice for surveys of research and experimental development.* The Measurement of Scientific and Technological Activities Series. 4th ed. Paris: OECD.
———. 1994. *Frascati manual—Standard practice for surveys of research and experimental development.* The Measurement of Scientific and Technological Activities Series. 5th ed. Paris: OECD.
———. 1997. *Review of the OECD-Eurostat PPP program.* Paris: OECD. http://www.oecd.org/std/ppp/ppps.htm.
———. 2002a. *Frascati manual—Standard practice for surveys of research and experimental development.* The Measurement of Scientific and Technological Activities Series. 6th ed. Paris: OECD.
———. 2002b. *PPPs and real expenditures—1999 benchmark year.* Paris: OECD.
———. 2003. *Research and development statistics.* (2003 ed.). Paris: OECD.
———. 2004. *STructural ANalysis (STAN) database.* Paris: OECD.
O'Mahony, M., and B. van Ark, eds. 2003. *E.U. productivity and competitiveness: An industry perspective: Can Europe resume the catching-up process?* http://www.ggdc.net/pub/EU_Productivity_and_Competitiveness.shtml.
Summers, R., and A. Heston. 1991. The Penn World Table (Mark 5): An expanded set of international comparisons, 1950–1988. *Quarterly Journal of Economics* 106 (2): 327–68.
van Ark, B. 1993. *International comparisons of output and productivity.* Groningen Growth and Development Centre Monograph Series no. 1. http://www.ggdc.net/pub/arkbook.shtml.
van Ark, B., and M. P. Timmer. 2001. PPPs and international productivity comparisons: Bottlenecks and new directions. Paper presented at the World Bank-OECD seminar, Purchasing Power Parities: Recent Advances, Washington, DC: http://www.oecd.org/dataoecd/24/0/2424747.pdf.